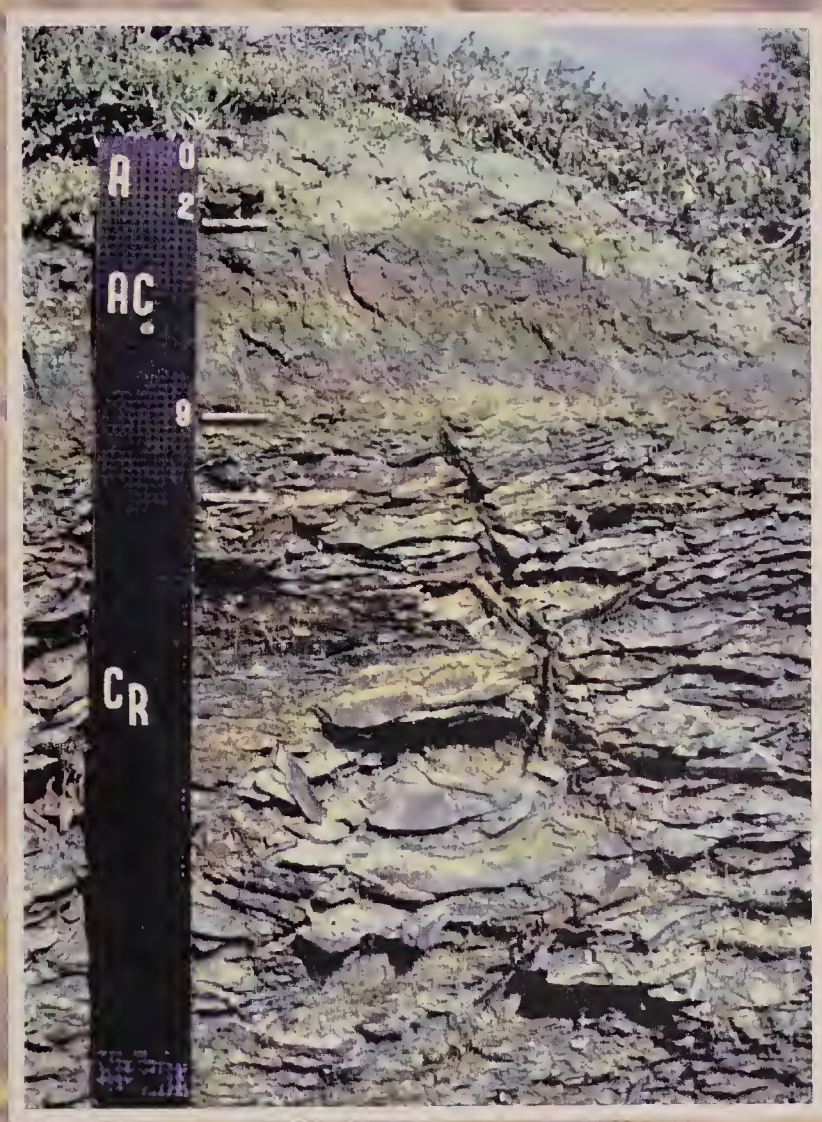
Defining and Assessing Soil Quality/Health on RANGELANDS

From the Ground Up—A Perspective on Rangeland Health

Understanding Soils



Soils forming in arid, wildland settings vary widely in physical, chemical, and biological properties and in their ability to function—

It Helps to Know...

PREFACE

"About the Notebook"

This notebook, Defining and Assessing Soil Quality/Health on Rangelands is developed to provide an assembledge of synthesized information and key references on Soil Quality/Health for BLM staff. The purpose is to integrate the concepts of Soil Quality into land health activities within the BLM, with the goal of improving and maintaining the health of our public lands.

Information on Soil Quality/Health has expanded and increased rapidly in the past 5 years and now includes an ever growing base of knowledge. Much of the information exists in scientific papers, unpublished reports, or has never been recorded and is not easily accessible by technical staff and managers. Also, much of the information is rarely synthesized and tailored to provide for effective application.

Organization of the Notebook

This Rangeland Soils Notebook is an assembledge of Soil Quality/Health information in a loose leaf notebook format with tabbed sections to provide easy access to key information by subject and most importantly, to provide for periodic insertions of new materials and revision of existing contents. The information in the various sections represents pertinent literature for developing a conceptual framework on Soil Quality/Health for technical staff and managers. Sections are brief by design with illustrations and graphics to facilitate a rapid assessment of information on specific topics. When additional information is required, reference is made to the reference list and the key references that are contained in the notebook.

Distribution of the Notebook

Initial distribution is being made to BLM State Soil Resource Leads, BLM Soil Scientists, and to other staff as a *prototype guide* for testing in the field, to critique and provide suggestions on format and substance as well as topics for inclusion.

Revisions and Supplements

Revisions and supplements will be made as necessary to meet current information needs and to provide new available information. Revisions for Bureauwide use will be transmitted by notebook notices with accompanying revised Table of Contents. Local tailored information can be incorporated in the section entitled "Local Soils Quality Information." This guide is intended to be field applicable, to provide answers, and to be guided by *field needs and inputs.* It is intended to provide a forum to share and correlate information and experiences.

Continued Activities

The initial notebook release contains mainly basic information and some "Key References." It is the intent in the future to include more specific basic field methods, techniques, and experiences

used to observe, identify, and interpret Soil Quality/Health as it relates to public land health. Special emphasis is placed on the development of information and guideline materials for the "Reading Soil Quality/Health" section, the "Hydrologic Characteristics - Watershed Function" section, and a Soil Quality/Health guide for rangelands. Efforts are also directed toward development of software packages to assist Soil Quality/Health evaluations.

Development of an accompanying video is proposed to incorporate slides to illustrate soil surface and attribute characteristics, site and setting characteristics, and to relate experiences. To successfully achieve the continuing activities will require the sponsorship and assistance of a BLM Soil Quality Team.

The BLM, Natural Resource Conservation Service (NRCS), and Agriculture Research Service (ARS) have worked in partnership during the past five years in developing Soil Quality/Health information and its application relevant to land health activities. This is outlined in the Report of Soil Survey Division Soil Quality Team located in the Introduction section of this notebook.

This Soil Quality/Health information source provides a "From the Ground-up Approach to Rangeland Health" and strongly supports and compliments the "BLM Land Health Initiatives." It provides background information and assistance for implementation of the Standards and Guidelines for Healthy Rangelands. The Soil Quality/Health information provided by this notebook is not limited only to rangelands, but is applicable to other lands. We invite your comments, recommendations, and *participation* in this activity.

Alan Amen
Soil Scientist
National Applied Resource Sciences Center

Introduction

Soil Quality/Soil Health

Report of the Soil Survey Division Soil Quality Team*

**An outline and approach to
incorporating soil quality/soil health into the
Natural Resource Conservation Service
and
Bureau of Land Management**

Soil Survey Division Soil Quality/Soil Health Team

*This report has been modified with additions to reflect applications relevant to land health activities within the Bureau of Land Management. The original report was released in 1995.

Team Assignment and Structure

The Soil Survey Division established an ad hoc team on soil quality/soil health in December 1993. Two charges to the team related to this report were:

1) develop a strategy to address soil quality/soil health issues and terminology for the Soil Survey Division and NRCS.

2) identify and develop indicators and criteria for evaluating and monitoring soil quality/soil health or sustain ability, and

The team consisted of Gary Muckel (team leader), Robert Grossman (research soil scientist), Carl Glocker (soil survey quality assurance), Ronald Bauer (forestry and range interpretations), Berman Hudson (forest ecosystem EMAP liaison), Betty McQuaid (agroecosystem EMAP liaison), Gary Tibke (conservation agronomist), Hari Eswaren (world soil resources), and Larry Brown (RCA liaison), Carol Franks and Tom Reinsch (range-ecosystem EMAP liaisons), and Lawson Spivey and Ben Smajiwood (National Headquarters soil scientists) were additional resource members. The U.S. Forest Service team member was Jerry Ragus. Al Amen of the Bureau of Land Management is liaison to the BLM efforts. The team sponsor was Maurice Mausbach.

The material within this report is a recording of many of the results of this team activity. Not recorded are the many presentations, contacts, and details of field procedures and programming needs. Several spin off teams and products are in the formulation stage for this subject area.

Executive Summary

Recent recommendations for national policy to conserve and enhance soil quality/soil health as a fundamental first step to environmental improvement has led to efforts by the Natural Resources Conservation Service (National Cooperative Soil Survey - Lead) to develop a strategy to address soil quality/soil health issues.

Included within this scoping issue paper are definitions for terms, identification of indicators and criteria for evaluating soil health, and recommendations for incorporating soil quality/soil health into farm and ranch operations, ecosystem-based assistance, national inventories, and other applications.

Spatial and temporal differences in soils confuse the application of soil quality/soil health. Soil quality is used as a term for the spatial comparison of different soils based on more enduring properties. Soil health is the evaluation of soil quality over time. This term reflects change over time as caused by management or natural events. Soil quality and soil health both include the capacity of the soil to sustain plant and biological productivity, maintain environmental quality, and promote plant and animal health. More specific functions are used to describe these general functions in the definition of soil quality.

Application of soil quality and soil health into the Natural Resources Conservation Service (NRCS) and Bureau of Land Management (BLM) can be accomplished by using the current field office technical guide structure, technical assistance responsibilities, and national resource inventory charges.

Opportunities for application of soil quality/soil health into the NRCS and BLM can be described by the following general to specific activities.

1) National/International Evaluation of the Condition of the Soil Resources.

Generate local. state, national, and world maps showing the status of soil quality. Soil quality maps are based on an inventory of soil quality indicators for current resource conditions.

2) National/International Resource Inventory for Trends.

Inventory and monitor base level soil health indicators to establish soil health changes over time and land use. Use with forecasts.

3) Target Areas for Conservation Assistance and Rangeland Health Concerns by Identifying Potential Resource Problems.

Use State Soil Survey Geographic Database (STATSGO) or National Resource Inventory (NRI) data for identifying areas at risk to soil quality degradation, such as areas subject to compaction, acidification, salinization, and loss of soil by wind or water erosion. Use a soil interpretation approach.

4) Evaluation of Soil Resources for Farmland Protection and Production.

Use prime farmland criteria to identify soil resources on the edge of urban areas that need protection and monitoring for possible contamination. Sort soil data bases for parameters for crop production.

5) Evaluation of Conservation Practices and Management Systems.

Monitor soil health changes with respect to effectiveness of conservation practices and management systems to improve soil health or the health of other critical resources.

6) Farm and Ranch Level Resource Problem Evaluation and Monitoring for Trends.

Develop checklists and tools for land users to record visual and easily determined indicators of soil health. Evaluate field resource problems and trends resulting from management effects. Create land manager ownership and involvement in soil health.

Provide ecosystem-based assistance to help to evaluate resource problems and quantify soil health changes. Utilize more sophisticated tools to measure soil health factors and changes with management inputs. The goal is to treat soil degradation early.

7) Healthy Rangeland Initiative (BLM)

This initiative, which provides for the establishment of rangeland standards and guidelines is dependent upon the effective rangeland monitoring results including applications of Soil Quality/Health. The requirement for public rangeland monitoring is driven by:

- Federal Land Policy and Management Act of 1976, charges the BLM to "prepare and maintain on a continuing basis, an inventory of all public lands and their resources to be kept current so as to reflect changes in conditions."

- Public Rangelands Improvement Act of 1978, reaffirmed a national policy commitment to inventory and identify current public rangeland conditions and trends on BLM land and to manage, maintain, and improve the condition of the rangeland so that it becomes as productive as possible for all rangeland.

Soil quality/soil health concepts provide many opportunities useful to the mission of the Natural Resources Conservation Serviceand the Bureau of Land Management. Full implementation will require involvement of all technical disciplines within NRCS and a close working relationship with the research community, other USDA agencies, and other partnerships.

Soil Quality/Soil Health - Report of the Soil Survey Division
Soil Quality Team

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Soil Quality / Soil Health

Report of the Soil Survey Division Soil Quality Team

A. Background to Soil Quality/Soil Health

The reference, *Soil and Water Quality: An Agenda for Agriculture,* by the National Research Council, provides an excellent background and literature citation addressing the importance and recommendation for future policy and agency directions to protect the soil resource and sets the stage for new strategies for the Natural Resources Conservation Service and Bureau of Land Management. The following statements are abstracted from this reference:

> *The 1990 Clean Air Act and Clean Water Act give national recognition to the fundamental importance of air and water resources. Soil resources are equally important components of environmental quality, and national policies to protect soil resources should be based on the fundamental functions that soils perform in natural and agroecosystems.*
>
> *National policy should seek to (1) conserve and enhance soil quality as a fundamental first step to environmental improvement; (2) increase nutrient, pesticide, and irrigation use efficiencies in farming Systems; (3) increase the resistance of farming systems to erosion and runoff and (4) make greater use of field and landscape buffer zones.*
>
> *National policies to protect soil resources presently are too narrowly focused on (1) controlling erosion and (2) conserving soil productivity.*
>
> *Soil productivity is not the only, and in some regions may not be the most important, reason to protect soil resources. Soil and water quality are inherently linked. Preventing water pollution by nutrients, pesticides, salts, sediments, or other pollutants will be difficult and more expensive if soil degradation is not controlled.*
>
> *The quality of a soil depends on attributes such as the soil's texture, depth, permeability, biological activity., capacity to store water and nutrients, and the amount of organic matter contained in the soil. Soils are living, dynamic systems that are the interface between agriculture, rangelands and the environment. High-quality soils promote the growth of crops and make farming systems more productive. High-quality soils also prevent water pollution by resisting erosion, absorbing and partitioning rainfall, and degrading or immobilizing agricultural chemicals, wastes, or other potential pollutants. The quality of some soils, however, is degenerating because of erosion, compaction, salinization, loss of biological activity, and other factors.*
>
> *Soil quality can be improved or degraded by management. Erosion, compaction, salinization, sodification, acidification, and pollution by toxic chemicals can and do degrade soil health. Increasing the protection the soil is afforded by crop residues and plants; adding organic matter to the soil through crop rotation, manures, or crop*

residues; and carefully managing fertilizers, pesticides, tillage equipment. and other elements of the farming system can improve soil quality.
Changes in agricultural productivity, water quality, and global climate are linked to soil quality through the chemical, physical, and biological processes that occur in soils.

The significance of soil quality degradation is greatest for those changes that are not easily reversible.

New national environmental policy should include: (1) new criteria to quantify soil quality; (2) redirection of national soil and water resource assessments to provide the information needed to determine the extent and seriousness of soil degradation; and (3) greater attention to soil management at the farm and ranch level.

If the conservation and enhancement of soil quality are to be the primary objectives of soil resource policies, methods for measuring changes in soil quality and predicting the effects of farming and grazing systems on soil quality are needed. Key indicators of soil quality need to be identified and used as the basis for monitoring the predicting changes in soil quality.

The development of methods to quantify changes in soil quality will require measurable indicators that are relatively easy to sample and not subject to extreme variation in time or space. This research effort should include:

-identification of the soil attributes that can serve as indicators of change in all soil functions and development of simplified models that relate changes in the selected attributes to changes in soil quality;

-standard field and laboratory methodologies to serve as indicators to measure changes in soil quality;

-a coordinated monitoring program that can quantify changes in the indicators of soil quality; and

-a coordinated research program designed to support, test, and confirm the models used to predict the impact of management practices on soil quality.

The National Resources Inventory should include quantifiable measures of changes using selected soil quality indicators and should be broadened to produce estimates of compaction, salinization, sodification, acidification, and biological degradation in addition to erosion.

Soil quality indicators and models should be used to set threshold levels of soil quality that can be used as quantitative guides to soil management Quantitative standards to quantify, the effect of erosion, compaction, salinization, biological degradation. and other processes of soil degradation on the minimum data set of soil quality indicators are needed to enable comprehensive and cost effective management of soil resources.

Measures of soil attributes in the checklist of soil quality indicators should be added to routine soil test reports, and the significance of measured levels of indicators should become part of the routine interpretations issued with soil test reports.

Within the last few years, many Federal agencies have changed their focus from a single resource to multiple resources. The Natural Resources Conservation Service (formerly the Soil Conservation Service) initiated Soil-Water-Air-Plant-and-Animal (SWAPA) concerns into the Field Office Technical Guide about four years ago. The U.S. Forest Service implemented soil quality standards or objectives about five years ago. The BLM, Rangeland Health assessments include soil quality/health evolutions.

Several soil quality efforts are progressing. The Natural Resources Conservation Service (NRCS) has teams established within the Soil Survey Division, and a Soil Quality Institute is planned. The Environmental Monitoring and Assessment Program MAP) of the Environmental Protection Agency includes soil quality. NRCS has full-time liaisons to EMAP Agroecosystem and Forest-ecosystem work groups plus contacts with the Range-ecosystem workgroup. The NRCS National Soil Survey Laboratory is doing laboratory work for EMAP on contract. Several divisions within the Soil Science Society of America are addressing soil quality. Many NRCS scientists are represented. Rodale Institute is concerned with soil and food quality connections. The National Soil Tilth Laboratory and other groups within the Agricultural Research Service have soil quality high on their research agenda. International activities are also active, generally tied to the broader issue of agricultural sustainability.

Several changes are forecast for the NRCS agenda. Coordinating efforts can be directed to focus on either resource problem areas or on our highest quality soils to maintain their viability. Soil quality interpretations can be used to identify these areas.

The current state of the resources is a frequent concern that directs attention and concern of local, state, and national leadership. Soil quality indicators can be assessed across the country to answer these concerns.

The trends of soil health can be assessed by monitoring the changes shown by soil indicators. Changes in some factors may forecast resource problems in another resource. Decreases in pH may mean increased mobility and uptake of heavy metals into food and water supplies.

A general assessment of soil quality provides an overall view of the food, fiber, and feed production capabilities of the nation. A general assessment provides a tool for planning where spatial distribution has application, such as anticipating the effects of major environmental insult.

A set of soil health indicators is recommended to be added to NRCS field office technical guides. The effects of recommended practices on soil health can then become integral in developing integrated farming and grazing system plans. A simple checklist of soil attributes serving as soil health indicators is recommended for field tracking of conservation practice effects grazing and management effects.

Technical assistance from NRCS, private consultants, cooperative extension, fertility testing laboratories, private industry, and others is available to provide quantification and evaluation to the land manager.

Ecosystem-based assistance by the NRCS and BLM expands conservation planning assistance and interpretations among all resources and encompasses not only individual farms and ranches but a watershed or other ecological bounded area. Resource assessment and evaluation, and maintenance or improvement of soil health are key elements to this assistance.

Conservation practice and land management recommendations can be improved by monitoring the effects on all resources and by evaluating the economic cost and value of maintaining and improving these resources.

B. Definitions

Soil quality and soil health are two terms used to report the physical, chemical, and biological condition of a soil area. These spatial and temporal comparisons of soils are sometimes confused.

1. Spatial comparisons

Soil variability is spatially represented on soil maps based on soil properties of the map unit components. The range in characteristics of soils is the result of soil-forming factors. The five soil-forming factors are parent material, climate, topography, living organisms (including humans), and time. The geographic variability of these factors provides for the spatial variability of soils. Where the processes are similar, areas of similar soils are predicted, verified, and consistently mapped.

The National Cooperative Soil Survey has prepared soil maps that delineate areas of similar soils at a level of detail commensurate with the intensity of use at the time the survey was conducted. Many soils in the United States have undergone changes because of the use and management applied to them. Extensive soil survey remapping of these areas has not always kept pace with these changes, but the soil maps and the soil data of the National Cooperative Soil Survey still represent the spatial variability of soils for use in soil quality interpretations. The published soil survey provides a base level soil quality when other data is not available. Soil survey also provides information about the susceptibility of the soil to damage and about the resiliency or fragility of the soil.

2. Temporal comparisons

Soil health is the evaluation of soil quality over time. Evaluations of soil health or soil condition are determined by monitoring changes of reference points and are expanded to represent particular soil ecological units at any scale. Soil changes can be either an improvement or degradation.

Improvement or degradation through management depends on the effects of the practices on the soil properties. A close tie between management practices and soil properties can be established by monitoring the effects of practices on soil indicators.

3. Definition of Soil Quality

For an orderly approach to the identification and analysis of soil related processes in a given ecosystem, the soil quality team established by the Soil Survey Division proposes the following definitions.

Soil quality is the capacity of the soil to sustain plant and biological productivity, maintain environmental quality, and promote plant and animal health. These general functions are described within ecosystem boundaries by the following soil functions:

-providing a physical and chemical environment for gas, nutrient, water, and heat exchange for living organisms;
-regulating the distribution of surface water to runoff or to infiltration, storage, and deep drainage;
-providing mechanical support for living organisms and their structures;
-buffering the life support system against thermal, chemical, gaseous, or other stresses:

-acting as a source, sink, and filter reducing contaminants that affect water and other resource quality.4. Explanation of Primary Soil Quality Functions

(a) - providing a physical and chemical environment for gas, nutrient, water, and heat exchange for living organisms;

Soil not only supports the life in or on it but also strongly influences all life on the planet. To perform this all important life support function, it has to function as a three phase system -- solid, liquid. and gas. It has to be able to provide the energy source to sustain life. or at least the ingredients from which the energy is derived, and it has to provide ambient conditions for life to exist.

To perform its function, the soil has to have a certain minimum volume, a mineral-chemical composition that provides necessary nutrients at critical times, mechanical features that provide the physical support for life, and a moisture and thermal environment that is conducive for growth. Soils are also subject to internal and external losses and additions, but quality is maintained as long as the basic function is not impaired.

(b) - regulating the distribution of surface water to runoff or to infiltration, storage, and deep drainage;

The soil receives water from precipitation or irrigation and is subject to removal of water by evapotranspiration and drainage. The hydrological soil function is concerned with soil conditions that mediate runoff and deep drainage. Runoff has a determining influence on the amount and rate of surface water delivery and flooding. It also influences water erosion, including both short- and long-range sediment transport. Deep drainage is a determining factor of the danger of degradation of water quality.

To perform its function, the soil has to have conditions that allow infiltration of water and the capacity to store water for release to plants. A number of influencing soil factors are inherited, such as slope and water-holding capacity. Others factors are use-dependent. These include near-surface infiltration rate for runoff and the internal soil water balance, which is subject to change by irrigation and the kind of crop for deep drainage.

(c) - providing mechanical support for living organisms and their structures;

The soil acts as the solid matter on and in which humans and animals build their structures and burrows. The strength of the soil for these purposes depends on the balance of solid and liquid. the particle-size distribution, and amount of cementation. Excessive strength or weakness in the soil decreases the suitability of the soil for use by humans or animals.

The soil also acts as the solid matter in which plant roots grow and thereby provides the foundation to hold plants erect. Although a certain strength is necessary to provide the mechanical support. roots must be able to grow and branch out. The soil permits this through the short-range variation of the strength. Structural units individually may have high strength; however, the strength between structural units in an assembly community is much lower. As a result, roots can grow and branch between structural units, while the assembly of structural units provides the mechanical strength required by the plant to remain erect. If the structure is weak or there is a massive condition. or if the planes of weakness are very widely spaced, and if the strength of the matrix is high (for example, rock), then root growth and branching may be limited.

Mechanical properties are largely inherited. Tillage practices, however, can determine whether there is compaction at shallow depth that would limit the downward growth of roots.

(d) - buffering the life support system against thermal, chemical, gaseous, or other stresses;

Soil has a very great capacity to mediate the temperature change that results from additions or removal of heat. An important reason is that soil material has a large heat capacity, particularly if it is moist or wet. Another reason is that soil is a relatively poor conductor of heat, with the value increasing as the water content increases. As a consequence, great additions or removals of heat require a relatively long period of time. The soil temperature, therefore, lags with the change in atmospheric temperature. with the lag greater as the depth increases. This lag during the growing season maintains rather constant daily temperatures below a very few centimeters.

Soil buffers chemicals through the large specific surface to which the chemical is exposed. This large specific surface may enhance the rate of breakdown of some chemicals and localizes certain chemicals if they are positively charged in solution and therefore subject to being held on exchange sites. Organic matter in the soil enhances the rate of transformation of certain chemicals to a less toxic form. Micro-organisms in soils can break down many organic molecules to products that are less of a threat to the environment.

The movement of gas is buffered by retainment in small pores where movement is slow and by physical sorption aided by the high specific surface. Soils have capability to remove gases from the air in much the same manner as does charcoal, but to a smaller degree.

(e) - acting as a source, sink, and filter reducing contaminants that affect water and other resource quality.

Soil serves as the biosphere for many living things and is also the interphase with the atmosphere and geosphere. The minerals it contains provide the nutrients necessary to support life. It also serves as a sink for additions to the system, coming as dust, dissolved materials in the hydrologic componen, or as by-products of the decomposition of live organisms. Many of the additions further provide nutrients of the food chain of living things.

Finally, soil serves as a filter for agrichemicals and other contaminants or additives to the soil. Soil retains many of these, thereby reducing the contamination of the hydrologic system. In some cases, the contaminants or additives are detoxified before release to the water system.

5. Definitions of Other Related Terms

(a) Soil health is the evaluation of soil quality over time. The measured values at the beginning of soil health monitoring serve as the base level values for soil health comparisons.

(b) Soil resiliency is the ability of a soil to rebound or the capacity to recuperate from a stated condition of soil health to the condition at the time of the imposed stress. (Eswaren, modified by SSD Soil Quality Team)

(c) Soil fragility is the ease with which a soil can change to an undesirable condition for soil functions. (SSD Soil Quality Team)

(d) Land capability is a grouping of soils based on their potentialities and limitations for sustained production of the common cultivated crops and pasture plants. (Ref. Ag Handbook 210, modified)

(e) Soil potential is the relative quality of a soil for a particular use, as compared with those of other soils in a given area. (Ref. National Soil Survey Handbook)

(f) Soil condition is the chemical and physical characteristics of soil as related to its ease of tillage, fitness as a seedbed, and ability to absorb store, and release water and nutrients for plants. (Ref. GM title 450)

(g) Soil tilth is the state of aggregation in soils. It is the physical condition of the soil in its relation to plant growth. Tilth closely parallels the term soil condition but is limited to the near surface physical soil properties. (SSD Soil Quality Team)

(h) Land degradation is the loss of utility or potential utility through reduction of or damage to physical social, or economic features or reduction of ecosystem diversity. Land is degraded when there is a mismatch between land/soil quality and land use. (Eswaren)

C. Degradation

Soil degradation processes reduce the capacity of the soil to function. Each process results in a loss, reduction, or damage to soil health. These processes are an outcome of both human activities and natural processes and are geographically specific. Soil quality indicators are specific to the kind of degradation. Soil quality indicators selected for use in any area should consider the most significant degradation processes in effect for that location.

The primary processes that can degrade soil function are:

erosion	temperature stress
compaction	moisture
acidification	moisture surplus
salinization	leaching
sodification	lost of biological activity
contamination	nutrient depletion
deposition	crusting
disaggregation	laterization (hardening)
burning	

Degradation is only one aspect that may provide for localizing soil health indicators. Soils vary in their inherent quality and in their fragility and resiliency to processes of degradation. The relative importance of the soil quality functions considered in soil health varies from geographic area to area. The value that society places on the functions of soil quality also vary from place to place. The sensitivity for off site concerns can affect the significance of the soil degradation process and corresponding soil indicator. One soil

function may take precedence over others. Checklists for the land manager can be localized to the degree needed.

D. Application

1. General

Application of soil quality into the Natural Resources Conservation Service can be accomplished by using the current field office technical guide structure, technical assistance responsibilities and national resource inventory charges. More emphasis is necessary to assist the land manager in recognizing resource conditions and in monitoring and recording information on soil health related to the practices that are applied. Assistance from all technical advisors can contribute to soil quality improvement. National resource inventories by all agencies are part of a responsibility to assess the condition of the land for long-term sustainable use. Soil quality provides a strong foundation to sustainable use and helps to link other resource concerns.

2. Levels of Application

Application of soil quality is conducted at four ecosystem levels. Each ecosystem level has a corresponding geographical subdivision, scale, and supporting database. The following chart illustrates these relationships.

Ecosystem Level	Geographical Level	Applicable Scale	Supporting Database
Region Subregion	National	<1:1 million	NATSGO
Section subsection	State	1:1 million to 1:100K	STATS GO
System/ subsystem	County	1:100K to 1:10K	SSUROO/ FOTG
Primary Mgt Unit	Field	1:10K to 1:1 K	FOTG/ Onsite

Each level has a bounded area of application and requires a minimum of data.

Various applications of soil quality are appropriate for each ecosystem level. The appropriate applications for the listed ecosystem level are listed below.

(a) Region/Subregion (national)

-Assessment of the state of the resources.
-Monitoring for trends of resource conditions.
-Strategic plans/policies for resource management.
-Identifying and targeting resource problems and mitigating technology changes.
-Defining research and technology development priorities.
-International environmental concerns, (global climate change, etc.)

-Offsite impact.

(b) **Section/Subsection (state, MLRA)**

-Assessment of the condition of the resources.
-Monitoring of trends of resource conditions.
-Strategic planning for resource management.
-Identifying and targeting resource problems and mitigating technology changes.
-Defining research and development priorities.
-Offsite impact.

(c) **System/Subsystem (county)**

-Assessment of the condition of the resources.
-Monitoring for program success, compliance.
-Identifying and targeting resource problems and mitigating technology changes.
-Implementation of conservation programs.
-Soil specific management.
-Onsite and offsite impact.

(d) **Performance Management Unit (field/farm)**

-Assessment of resource condition.
-Monitor for trends (soil test for fertility).
-Conservation planning and implementation.
-Risk management and analysis.
-Soil specific management.
-Onsite impact.

E. Opportunities for Application

The following parts discuss opportunities for application of soil quality/soil health.

1. National/International Evaluation of the Condition of the Soil Resources

Status of the resources for map output at the local, state, and national level can be presented with an inventory of soil quality indicators for current resource conditions.

The current state of our soils with respect to compaction, salinity, acidity, contamination by heavy metals or pesticides, biological activity, and carbon sequestration probably can only be obtained by sampling for these characteristics.

Field procedures and laboratory support are needed.

Presentation of the information varies by scale. Major land resource areas are suited to national status maps. State soil survey geographic data base (STATSGO) map units are suited to state and county or watershed status maps.

2. National/International Resource Inventory for Trends

(a) National resource inventory level

Monitoring soil quality for national objectives of sustaining resources provides information on the trends of resource conditions across the United States. The NRCS National Resource Inventory crosses land uses and is carried out currently on a five-year frequency. Both remote and ground sampling techniques can be used. The success of agencies and legislation can be evaluated based on the changes or trends in soil quality from the beginning of monitoring.

Besides the NRCS National Resource Inventory which excludes Federal land, the EPA Environmental Monitoring and Assessment Program and the USFS Forestry Inventory and analysis are reviewing indicators. The recent publication *Rangeland Health* by the National science Foundation and the proposed Grazing Lands Initiative emphasize monitoring and evaluating soil quality as part of monitoring rangeland health. NRCS, EPA, ARS, BLM, and USFS are coordinating indicator evaluations.

Indicators for this level can be carried out by using agency specialists. Because of the sheer numbers of sample points needed, the indicators must be obtained within minimum time requirements.

(b) Soil quality indicators for national resource inventory

Cropland

- Acid alkalinity
- Aggregate stability
- Infiltration
- Salinity
- Thickness of horizons

Forest

- Acidity
- Infiltration
- Organic matter (wood. woody material, & duff)
- Soil cover
- Thickness of topsoil

Rangeland

- Aggregate stability
- Alkalinity
- Cryptogram cover
- Deposition
- Ground cover
- Infiltration
- Nutrient cycling
- Salinity
- Soil solum structure

3. Target Areas for Conservation Assistance by Identifying Potential Resource Problems

Such available data as STATSGO or NRI data can be sorted through selection of soil, climate, and land use parameters for identification of those areas that are susceptible to degradation by erosion, compaction, acidification, salinization, etc.

Based on where the degradation processes occur, those soils that have the greatest risk of being damaged by each of the various degradation processes can be identified by using a sorting procedure. The State Soil Survey Geographic Data Base (STATSGO) has the best potential to address these potential target areas. Identifying the land use would strengthen the value of this sorting procedure.

The relative importance of the functions of soil quality and the relative importance of the processes of soil degradation vary from geographic area to area. Soils vary in their inherent quality. Certain soils are more vulnerable to the loss of one or more components of soil quality. The value that society places on the functions of soil quality vary from place to place. Management may place a higher precedence on one function than on others.

With the importance of degradation varying from area to area, trying to identify where these processes are most important may be helpful. The following processes can be accessed using current soil databases and other data using the geographic information system:

wind erosion and water erosion compaction
acidification
salinization and sodification deposition
moisture stress moisture surplus leaching
crusting

The parameters in the databases that can be used to sort for soil degradation potential are listed with the degradation process.

Erosion

(a) by water

where R K LS / T > 8 or other number greater than one.

but R and LS missing from STATSCO. Rainfall intensity factor "R" as a map product exists, but a geographic data layer compatible to GRASS software is needed. The equation is sensitive to the time period selected for the climate factor. Using the standard "normal" period of 1961 to 1990 for climate database entries changes formerly used R factors. Slope length is a new data element for the National Soil Survey Information System but currently is not available in STATSGO. This element would need to be estimated or obtained from digital elevation models. T factor is currently being adjusted.

(b) by wind

where C 1/ T > 8 or other number greater than one.

but C is not in geographic or tabular database, a geographic data layer compatible to the GRASS software for the climatic "C" factor is needed.

Compaction

Compaction is greater with cool, wet springs, non-expanding clays, low content of silt. high content of sand and clay, and low content of organic matter. The Unified soil classification classes describe many of these conditions. Land use may be a needed component.

Acidification

surface pH below 7.8
noncalcareous surface 10 inches

Salinization and sodification
moisture deficit
EC > 2 in upper parts

Deposition
flood plains

Moisture stress
ustic moisture regime
xeric moisture regime
dryland cropping areas (capability)

Moisture surplus
udic moisture regime and wetter

Leaching
low organic matter <0.5
low clay or cation-exchange capacity
soil pesticide leaching index

Crusting
R rainfall intensity
silt to sand ratio
organic matter to clay ratio
SAR

GIS analysis is needed with maps being the primary products.

4. Evaluation of Soil Resources for Farmland and RangelandProtection and Production

A general soil health evaluation provides the kind of documentation pertaining to general questions of plant growth and environmental degradation at a level of generality similar to that described in the soil surveys. Available data in map unit interpretation records in STATSGO or NRI can be sorted for those properties that are important in the production of crops.

Available soil data can be classified into groups that have various levels of functional needs.

High-quality soils can be identified from low-quality soils for policy decisions on protection and enhancement.

Soil survey information can provide a base level soil quality evaluation for different soils Quantities are obtained from the soil survey database. Soil climate, slope, particle size, permeability, and many internal soil properties are used. Many of these are invariant properties that do not lend themselves to soil health monitoring, but many have components that will reflect changes in management.

The following generalized procedure has been proposed:

(a) Quantities for soil quality evaluation
A generalized placement of properties is used for different categories. These are:
Soil climate
Slope

Particle size
Permeability
Minimum of other internal properties

Each of the following individual properties are rated 1 through 5. Nearness to the surface is weighted into the evaluation.

(1) Soil Climate is ranked using temperature and moisture regimes
Warm, moist sites are ranked highest and dry or cold sites lowest.

(2) Slope is ranked by slope classes
Slopes of less that 2% are ranked highest; those of more than 25% the lowest.

(3) Particle size has several components that are ranked
The ranking considers coarse fragments, the fewer the better. High silt and very fine sand content, lower sand content. and high ratio of organic matter to clay are desirable. Ranges in clay for class placements are dependent on the clay activity and on the organic matter to clay ratio. The higher the clay activity, the less clay desired. Optimum ranges of clay are defined; higher or lower amounts are less desirable.

(4) Permeability uses steady ponded infiltration,, permeability class, and deep water movement
Ranked highest are those soils that allow for quick entry into the soil but moderate rates of deep water movement.

(5) Other internal properties considered are:

Organic matter
Organic matter percent of 0 to 8 inch layer
OM >4% is ranked highest, OM <*0.5* is ranked lowest.
Organic carbon areal
A ranking of the weight of organic carbon per unit volume.
Dispersion resistance index
The ratio of OM to the mineral CEC of the surface to 8 inches is a prediction of wet aggregate stability. The greater the ratio, the higher the ranking.

Fine-earth air-filled porosity at field capacity
Air-filled porosity of more than 20% is highest, < 2% is lowest.

Bulk density exceeding root restriction
The bulk density at root limitation varies by particle size. The soils with the greatest difference between calculated porosity for the assigned bulk density and that at the bulk density where root restriction is initiated are ranked the highest.

Available water supply (AWC/PE-PPT)
Ranked highest are those soils that supply water to plants for the longest time while evapotranspiration is at a maximum.

Cation-Exchange Capacity (CEC)
Ranked highest are those soils with CEC of more greater than 15, and ranked lowest are those with CEC of less than 3.

pH

pH of neutral is ranked highest, pH > 9 or < 3.5 the lowest.

Salinity

Electrical conductivity of less than 2 mrnhos/cm is ranked highest. lowest are those soils of more than 16 mmhos/cm.

Sodium Adsorption Ratio (SAR)

SAR less than 2 is ranked highest. SAR more than 13 the lowest.

The rankings are commonly an interrelation of different properties.

With assignment of weighting factors for soil function and assignment of value to classes this evaluation closely approximates a soil quality index.

5. Evaluation of Conservation Practices and Management Systems

Monitoring soil quality changes after conservation practices have been incorporated can lead to documentation of practice effects and improved of conservation practice recommendations. Section V of the field office technical guide appears well suited for this documentation.

6. Farm and Ranch Level Resource Problem Evaluation and Monitoring for Trends

(a) General

Evaluation of soil health is primarily aimed at those soil properties that reflect changes that are management influenced. Non-enduring properties are generally not available in the soil survey database. A use-dependent database is needed if we are to monitor the change in these types of properties. Section V of the FOTG provides the location.

An evaluation of soil health is very similar to Soil condition, as used in the field office technical guide. Soil condition as defined in the FOTG only addresses crop production and therefore is presently limited for use with other functions.

The indicators selected to monitor and evaluate soil health vary depending on the objective of the monitoring and on the available expertise. Two levels of application, field and resource area. require a different frequency of monitoring and have different objectives. The field level objective is to guide management to improve the health of the soil. The resource area level provides a measure of success for legislation and provides current status for national objectives.

The field level is subdivided into two levels of expertise. The land manager level assumes a constant observer where temporal indicators can be most useful. The assistance level assumes more technically trained specialists with expanded equipment and expertise to provide understanding and quantification to the land manager.

(b) Land manager application

Soil health monitoring and evaluation provide the opportunity to greatly expand and enhance the resource evaluation step of conservation planning and ecosystem-based assistance. Soil health can be monitored and evaluated to a great degree by the land manager. Indicators of soil health can be observed.

recorded. and evaluated by the land manager if the tools to do so are provided. A checklist of simple field indicators is suggested. This checklist should be localized. The effects of management can be observed and recorded by those individuals most affected by their own inputs.

Development of an understanding of the effects of management and the importance of soil health is important to create at the land manager level.

(c) Ecosystem-based assistance application

Assistance from technical advisors enhance the land manager's own evaluations. Advisors with the Natural Resources Conservation Service, the Bureau of Land Management, the Cooperative Extension Service equipment and chemical dealers, private consulting companies, testing laboratories, and other groups can assist the land manager to evaluate field soil health monitoring and enhance the monitoring with more sophisticated and quantifiable tests.

The list of recommendations and alternatives that enhance soil health and other resources will improve as more evidence is gathered on the effects of management practices on soil health.

(d) Example areas for separate land manager checklists

Land manager, farmer or rancher checklists need to only address the indicators of soil health that are applicable to the local area and type of land use. The following subdivisions are suggested as example areas for the use of different checklists:

Agroecosystems-cultivated areas
- Humid Midwestern and Eastern states
- Irrigated West
- Great Plains
- Southern and mid-Atlantic

Forest-ecosystems-forested areas
- Southern and mid-Atlantic
- North-central and East
- Western mountains and foothills

Range-ecosystems-grazing lands
- Pastureland
- Mid and tall prairie
- Arid rangeland
- Arid riparian rangeland

(e) Checklists and soil health indicators for land managers

Cultivated areas in humid Midwestern and Eastern states
- Acidity
- Aggregate stability
- Earthworms
- Ephemeral gullies and rills
- Exposed subsoil
- Rapid runoff

Residue breakdown
Restricted rooting
Sediment deposition
Slick surface appearance
Surface crusting
Thinning A horizon
Uneven crop growth
Weed infestation and disease outbreaks

Cultivated areas in irrigated West

Alkalinity
Crusting
Disease outbreaks
Exposed subsoil
Infiltration
Restricted rooting
Salinity
Sediment transport (furrow)
Uneven crop growth

Cultivated areas in the Great Plains

Acidity
Aggregate stability
Ephemeral gullies or rills
Exposed subsoil
Infiltration
Residue breakdown
Restricted rooting
Salinity
Sediment transport
Soil blowing
Soil build-up along fence lines
Uneven crop growth
Weed infestations and disease outbreaks

Cultivated areas in Southern and mid-Atlantic

Acidity
Ephemeral gullies and rills
Infiltration
Nutrient depletion
Poor growth
Restricted rooting
Sediment transport
Weed infestations and disease outbreaks

Forested areas in Southern and mid-Atlantic

Acidity in the A and E horizons
Organic matter content of litter and 0 horizon
Thickness of litter and 0, A. and E horizons
Total carbon and total nitrogen in A horizon

Forested areas in North-central and East
(same as souther and mid-Atlantic???)

Forested areas in Western mountains and foothills
Fire effects (nitrogen loss, soil structural loss,
loss of soil organisms, loss of cover,
and water-repellent layers)
Organic matter (wood, woody material. & duff)
Soil cover
Soil porosity (bulk density or infiltration)
Topsoil thickness

Pasture-land

Mid and tall grass prairie

Arid rangeland
Aggregate stability
Crusts
Cryptogram cover
Ground
Infiltration
Pedestals
Plant reproductive status
Rills and gullies
Species diversity
Vertical rooting
Weed infestation

Arid riparian rangeland
Alkalinity
Bulk density
Deposition
Gullies
Plant cover
Salinity

(f) Soil health indicators for technical assistance to managers

These indicators are intended to be more quantitative and require more specialized skills than those used for land manager checklists.

Standard indicators (these apply to all land uses)
infiltration
organic matter
thickness of horizons

Special needs indicators
acidity/alkalinity
aggregate stability
biological activity-nematode relations. ants, etc.

bulk density
heavy metal contaminants
ergosterol
nutrient status
pesticide buildup
respiration
salinity
water-holding

7. **Rangeland Health Assessment**

F. Future Workload in Soil Quality/Soil Health

Continued networking with the following groups:

ARS-National Tilth Laboratory and Pullman WA group
EPA liaisons
NW Area Foundation
USFS
Range ecosystem
ASA Soil Quality Working Group-John Doran
Joranado Experiment Station-Jeff Hormicker
NTCs or multi-discipline work units
BLM-Glen Secrist and Al Amen

Contacts to be cultivated:

Range health-Keith Wadman-GLA
National Park Service-Larry Pointer
NHQ coordination
Contaminants

Continued work or initiatives:

GIS access to soil degradation areas
Review and testing follow-up on indicators used
Scorecard development with NTC and other disciplines
National FOTG changes in policy
Biological indicators
Incorporation of indicators into fertility testing programs
Soil health kit makeups
Marketing plan development and implementation
Fact sheets on soil quality issues
Procedural manual on soil quality to address test and monitoring and sampling processes
Soil health kit construction
Travel for coordination and for testing indicators
Vacuum infiltrometers

Research needs

Support EMAP liaisons
Heavy metal contamination expertise and support to SQ
Development. testing, and improvement of soil health indicators
Tie to conservation practices-NTCs and ARS

Training to district conservationists. area resource soil scientists, and others

Structure and staffing

Lead scientist or coordinator from National Soil Survey Center working with Soil Quality Institute

G. Soil Quality/Soil Health-Related Activities

1. Global climate change-organic carbon monitoring
2. EMAP-soil quality indicators development and testing

3. NRI-utilization of soil quality indicators
4. FOCS-programming soil quality factors
5. Agronomy-practice effects prediction
6. FOTG-conservation practice physical effects
7. Grazing-lands initiative-range health soil factors
8. Sustainability-international issue
9. Soil degradation evaluation-targeting efforts
10. Legislative formulation
11. Soil Tilth Laboratory-soil management effects, soil quality indicators, soil quality index
12. Soil Health Kit-soil quality indicators
13. Soil Biological Working Group
14. ASA Soil Quality Working Group
15. NRC actions-Soil and Water Quality. Range Health
16. BLM Rangeland/Soil Health Assessment
17. Northwest Area Foundation-testing indicators
18. 1890 schools-sustainability and indicators
19. Forest Service-monitoring in place
20. Oregon State Univ.-biological indicators on forest land?
21. Use dependent database-team established
22. Productivity models-cash rent equalization and crop function
23. RCA-model development
24. Soil Quality Products Team
25. Soil Quality Institute

H. Supplemental Tables

Table 1. - Summary of Soil Properties Important to Plant Growth

PROPERTIES	PLANT NEEDS				
	Support	H_2O	Air	Nutrients	Physical
Aeration			X		
Aggregating		X	X		X
AWC		X		X	
Bulk density		X	X	X	X
CEC				X	
Depth to restriction	X	X	X	X	X
Erosion resistance	X				
Infiltration		X			
Nutrient availability				X	
Organic matter		X	X	X	
pH				X	
Rotting volume	X	X	X	X	
Salinity		X		X	

Structure	X	X	X	X	X
Surface stability	X				
Temperature		X	X	X	X
Texture	X	X	X	X	X

Table 2. - Summary of Soil Function Properties Important to the Hydrologic

Barriers to water movement
Coarseness of texture
Continuity of pores
Infiltration
Permeability
Soil aggregation
Soil structure
Surface roughness
Surface slope
Water holding capacity

Table 3. - Summary of Soil Properties Important to Buffering Function

CEC
erosion resistance
organic matter
pH
soil moisture
soil temperature
soil texture

Table 4. - Listing of Potential Soil Health Indicators

Visual indicators of soil health

- adjacent deposition
- bare patches
- cloddiness
- crusting
- dunes
- erosion
  - class
  - number of rills and gullies
  - phase
  - runoff
- evidence of deposition

- plant growth
  - crop color
  - uneven growth
- slick spots
- soil cover
- soil use
- subsoil exposure

Physical soil health indicators

- aeration
- aggregate stability
- aggregation
- amount of coarse fragments
- available water capacity
- bulk density
- crusting
- erosion potential-wind and water
- hydraulic conductivity
- infiltration
- macropores
- mechanical strength
- penetration resistance
- permeability
- pore size distribution
- porosity
- reconstituted bulk density
- residual porosity
- rooting limitation
- soil water content
- structure
- structure form-porosity, pore size distribution, pore continuity
- structure resiliency
- subsoil aeration porosity
- temperature
- texture
- thickness of topsoil
- water erosion potential
- water-holding capacity
- water supplying capability
- wind erosion potential

Chemical indicators of Soil health

- acidity/alkalinity
- cation exchange capacity
- carbon
  - cycling
  - labile carbon
- CO_2 evolution
- contaminates
- exchangeable calcium

exchangeable magnesium
exchangeable potassium
exchangeable sodium
ion exchangeable sulfur
exchange capacity
metal oxide content
microtox bioassay
mineralization
nitrogen
    cycling
    mineralizable nitrogen
    ratio of mineralizable N2 to carbon
    status
    total N
nutrient
    availability
    leaching
    status
organic matter
    distribution
    quality
    quantity
    rate of organic matter breakdown
phosphorus
    exchangeable
    organic phosphorus
    total
plant bioassay
    salinity
    type and amount of clay mineral

Biological indicators of soil health
    active carbon active nitrogen
    biological activity disease resistance
    ergosterol content
    hyphal length
    invertebrate population-abundance, biomass, density, richness
    microbial biomass
    organisms-nematodes, earthworms, ants, ground beetles
    residue decomposition
    respiration

Assessing The Quality of Rangeland Soils

Rangeland soils present unique challenges and opportunities for assessing soil quality. Three characteristics in particular distinguish rangeland soils from cropped soils: (1) spatial variability in rangelands tends to be higher than in cropped systems; (2) temporal variability is high because many biological and physical processes depend on a limited and frequently unpredictable supply of soil moisture; (3) the land often has many uses in addition to food production.

While all three characteristics present obstacles to the development of reliable soil quality indicators each also present additional opportunities. Patterns of both spatial and temporal variability can be quantifiable attributes of the system that may provide additional information about soil processes.

Conflicting definitions of soil quality are often implicitly, but not explicitly, based on particular value or use. These conflicts may be resolved using an alternative paradigm in which soil quality is defined only with respect to the soils capacity to fulfill clearly defined functions. Rating for individual functions can then be compared for a variety of values and land uses.

Spatial Variability

The spatial variability of many rangeland soil properties is extraordinary high when compared with typical land under cultivation. This high level of variability occurs at a variety of scales, from regional to microsite.

At the regional level, rangelands may occur on all arable soil, as well as on soil which have little or no potential for crop production. In mountainous and arid regions, this may include land on which little soil development has occurred. On a smaller scale, a single management unit within a region may cover several square kilometers and include a wide variety of land forms and landscape positions spread over more than one watershed. Each unit may include several soil orders. Soil depth and summer soil water potential may vary by several orders of magnitude.

Spatial variability in soil properties is clearly related to differences in soil and ecosystem functions. In many cases, relatively small areas make a large contribution to a particular function. For example, in arid and semi-arid mountainous regions, the majority of palatable biomass production often occurs on deep, well-watered riparian-zone soils. Likewise, a relatively large proportion of resource cycling in shrub lands occurs beneath shrub canopies and in the rhizosphere of widely-scattered grass clumps.

Challenges - A high level of spatial variability clearly presents a problem for sampling. Simple random sampling risks missing small areas that make a large contribution to ecosystem function. Even if these areas are included, a simple average across all landscape units and vegetation micro sites may not accurately represent true soil quality at a site. For example,

average soil properties could be quite similar for all annual grassland and for a shrub land, due to cancellation of values in shrub and intershrub spaces. Finally, the high level of variance associated with applying a random sampling pattern over a diverse system may make it nearly impossible to detect changes in soil quality without resorting to a level of replication which is beyond the budget of most programs.

Opportunities - While high spatial variability presents a problem for standard sampling and analysis approaches, variance can often be limited by careful stratification. Strata can be nested from the landscape to the microsite. Vegetation patterns and condition, landscape position, topography, parent material, and distance from disturbance foci can all be used at a variety of scales.

Changes in soil quality in some strata may also indicate changes in other strata. For example, increases in soil depth in a depositional area could indicate increases in erosion rates on slopes above. Recent advances in geographic information systems (GIS) and landscape ecology facilitate identification of strata that are likely to be linked.

Temporal Variability

Temporal variability in rangelands is high and relatively unpredictable. This is largely due to the strong dependence of many physical and biological processes on soil moisture in many rangeland systems. Most tingerate rangelands are characterized by low and extremely variable annual precipitation and high summer evaporation demand. As a result, soil moisture is frequently limiting for both plant growth and soil biological activity, particularly during the growing season.

At least four approaches may be taken to control variability within time periods. Each provides opportunities, although not without limitations: (1) restrict measurements to properties that are relatively insensitive to season and weather; (2) remove temporal variability through modeling; (3) sample frequently; (4) restrict sampling to defined periods.

Multiple Use Demands

Perhaps the greatest challenge to assessing soil quality for rangelands is that they are valued for a variety of different uses. Societal demands on nearly all agricultural lands have increased. In addition to food, fiber, and timber production, rangelands are valued for wildlife, bio-diversity, recreation, watershed and groundwater protection.

Each use is associated with at different ideal vegetative community structure. Different communities are associated with different soil properties and spatial patterns of those properties.

Summary and Conclusions

High levels of spatial and temporal variability increase the challenge of soil quality

assessment in rangelands. Interpretations of the data is confounded by competing views on soil quality that are often related to the values that individuals place on the land. However, both the high level of variability and the multiple demands on the land can be viewed as opportunities to introduce new approaches.

NOTE: Information was excerpted from the article entitled, "Assessing the Quality fo Rangeland Soil: Challenges and Opportunities" by Jeffrey E. Herrick and Walter G. Whitford.

ASSESSING THE QUALITY OF RANGELAND SOILS

Rangeland soils present unique challenges and opportunities for assessing soil quality.

1) Spatial variability is greater than cropland.

2) Temporal variability is high because many physical, chemical, and biological processes depend on limited and unpredictable supply of moisture.

3) Rangelands often have multiple use demands.

Utah Urban
Soil Quality
Networks Mtg.
June 8-9, 1995
Reno, Nevada

NOTES ON BUREAU OF LAND MANAGEMENT (BLM) NEEDS FOR TECHNOLOGY AND RESEARCH RELATING TO SOIL QUALITY AND HEALTH

BLM Stewardship

Rangeland managed by the BLM encompasses about 177 million acres of the total Federal ownership. Through a permitting system, approximately 17,800 grazing permittees, primarily in the 16 Western States, use BLM rangeland "allotments," or designated areas of use for livestock grazing.

The purpose of BLM's Rangeland Reform '94 is to carry out a rangeland management program to improve ecological conditions while providing for sustainable development. The proposed changes will enable the BLM to better manage public rangeland by ensuring proper functioning of rangeland ecosystems. This will maintain or improve biodiversity, while supporting other important uses. Improving the condition of riparian areas is of particular concern.

One of the key concerns and needs addressed in this reform proposal includes:

- Restoring and improving the ecological condition of the rangeland, including riparian areas, and managing for biodiversity and sustainable ecosystems through national standards and guidelines.

Ecosystem Management

The most effective way to address the challenge of restoring rangeland ecological conditions is to manage the land in accordance with the principles of ecosystem management. Management of individual components of ecosystems for immediate needs is balanced against management centered on long-term goals and objectives targeted to the entire ecosystem. Ecosystem management recognizes that people and their social and economic needs are also an integral part of ecosystems.

Shifting to ecosystem management is a significant change in direction for the BLM and offers opportunities to enhance the resources it manages. Currently, efforts are underway to implement ecosystem management on all BLM lands, encompassing all resources and values.

To accomplish this restoration of ecological conditions, National standards and guides are being developed for livestock grazing to provide a basis for making consistent decisions and to allow prompt and measurable progress in improving ecological conditions.

Implementation

National standards and guidelines will be used to ensure livestock grazing occurs in a manner compatible with properly functioning ecosystems and consistent with the principles of ecosystem-based management. They would be implemented through existing policy and,when they are in conformance with land-use plans, would be incorporated in grazing permits and leases.

National standards and guidelines would serve as the "umbrella" for supplemental regional standards and guidelines for areas such as the Great Basin, Pacific Northwest, Colorado Plateau, Northern Rockies/High Plains, and the Black Hills of South Dakota. The regional standards and guidelines would be developed and applied where appropriate.

Development of Standards and Guidelines

The BLM proposes to integrate a series of standards and guidelines into its national direction for livestock grazing in rangeland ecosystems. These are minimum conditions BLM will require to ensure ecological health and conditions concurrent with livestock grazing. BLM's goal for rangeland management and these standards and guidelines provide direction and authority to local managers.

The minimum information needed to determine properly functioning conditions of the ecosystem components is contained in three checklists. These checklists are categorized to apply to all components of rangeland ecosystems, the upland component, the riparian-wetland component, and the aquatic component.

Upland Component Guidelines and Checklists

Uplands are most commonly the largest component of the watershed. Most precipitation enters the watershed via uplands, so the condition and treatment of uplands directly affects the health and functioning of the rangeland ecosystem.

We are currently developing rangeland health assessment guidelines for the upland component. These guidelines involve soil, vegetation, and topography indicators, which will be used to interpret rangeland condition and trend. A large share of the BLM rangelands occur in arid and semi-arid ecosystems where vegetation cover is more sparse with higher percentages of bare soil surface areas. Effects of surface litter; surface roughness; vegetation type, composition and arrangement; and soil surface condition strongly influence rangeland health in these arid rangelands. Also, more emphasis needs to be placed on the effect of wind erosion.

Technology and Research Needs

The following are some suggested technology and research needs relating to arid and semi-arid rangelands:

- Data on key physical and chemical soil attributes to quantify and evaluate changes in soil quality/health for various grazing systems.

- A minimum set of data must be identified to develop scientifically valid criteria for soil quality/health assessment and monitoring, relating to soil stability to wind and water erosion.

- Research should be undertaken to develop simple techniques for assessing soil quality and health that can be used easily in the field, particularly where technical resource specialists are limited.

- Additional information is needed to identify soil-tilth conditions for key soil types and micro climates as related to various grazing systems.

- The effects of erosion on the physicochemical nature of rangeland soils, on organic matter, the activities of microbes, soil structure, and soil fabric.

An Additional Note

The BLM has been participating with the Natural Resource Conservation Service (NRCS) Soil Quality/Soil Health team led by Gary B. Muckle, Soil Scientist, National Soil Survey Center, Lincoln, Nebraska. This team's efforts have been very helpful in identifying and developing indicators and criteria for evaluating and monitoring soil quality/soil health and sustainability.

Soil Quality Assessment

Reading...

Soil Quality/Health

Shovel "Slice" sample of Barx fine sandy loam soil—showing platey compacted layers and other features.

This section presents information on basic field methods, techniques, equipment, and experiences used to observe, identify, and interpret soil quality/health.

Reading Soil Quality/Health

Emphasis is place on preparing information relating to basic field methods, techniques, equipment and experiences used to observe, identify and interpret Soil Quality/Health. (This section requires graphics support - including slides and color illustrations and is expensive. Currently, working with NRCS and ARS in developing Soil Quality Information Sheets tailored for Western Rangelands).

Topics considered:

(1) Sensitive Soil Properties and Soil Health
(2) Soil Structure Changes
(3) Soil Organic Matter Changes
(4) Soil Aggregrate Size and Stability
(5) Soil Surface Micro-Topographical Relief Influences
(6) Chemical and Physical Soil Crusts
(7) Soil pH and Salinization
(8) Nutrient Cycling

From The Ground Up — A Perspective on Rangeland Health

Knowing the Land

Integrated landscape analysis approach for soil survey enhancement and ecological site inventories.

Data

Climate Data

Topography (Slope, Aspect, Elevation) *

- Digital Elevation Model (DEM) Data *

Geology and Soil Parent Materials

- Geologic formation, member, & sediment properties
- Geomorphoric processes
- Spectral data (TM)
- Geologic interpretations

Vegetation (Types & Cover)

- Spectral data (TM)

Existing Soil Information

Land Use

Process

Soil Pre-Map Preparation

- Composite resource and ancillary information by overlay process
- Extrapolate soil information from selected sampled areas and existing soil data
- Map unit design (based on needs)
- Delineate soil map units
- Aerial photograph (stereo and interpretations)

Field Verification and Pre-Map Refinement

- Field observations and sampling
- Refine delineations
- Record field notes
- Complete soil map unit descriptions

Using GIS Technology

* Soil Survey Enhancement on Rangelands and Wildland Areas - Emphasizes use of geologic and topographic data to supplement soil and landscape interpretations for areas of shallow and medium depth soils, and geologic exposures.

Final Soil Map & Accompanying Attribute Data

Understanding Soil Quality/Health

Soil Attributes

Physical

Parent material
Soil texture
Coarse fragments
Soil structure
Effective soil depth
Soil horizon thickness

Chemical

Organic matter
Salinity
Alkalinity-(reaction)
Calcium carbonate
Nutrients (fertility)

Biological

Soil organisms
Microorganisms

Concerns addressed by soil quality

Loss of soil material by erosion
Deposition of sediment by wind or water
Compaction of layers near the surface
Soil aggregation at the surface
Infiltration reduction
Crusting of the soil surface
Nutrient loss or imbalance
Pesticide carryover
Buildup of salts
Change in pH to an unfavorable range
Loss of organic matter
Reduced biological activity and poor residue breakdown
Infestation by weeds or pathogens
Water quality

Reading Land Health

Rangeland Health Assessment (Interface)

- *Physical and Biotic Environment*

Linking with Standards and Guidelines Implementation

Soil Quality Sub-Sample (Field Methodology) Approach

1) Soil Identification and Verification

- Identify the plant growth material
- Correlate to ecological site

2) Setting and Site Characteristics

- Climate
- Landform and micro-relief
- Associated land features

3) Soil Quality Evaluation

- Sample basic soil attributes and near-surface (30 cm) morphology
  - Physical - Texture, structure, aggregate stability, crusts zones of bulk density
  - Chemical - pH, EC (salt), OM
  - Biological

4) Soil Sample Collection

- Primary surface sample

Provides plant growth medium and setting information in a sequence for rangeland vegetation and health evaluations.

Soil quality

A diagnostic system to measure the health or quality of a soil can be likened to a medical clinic for assessing human health. If an individual goes to a medical doctor for a check-up, the doctor will request certain key measurements such as temperature, blood pressure, heart beat, and perhaps a few blood characteristics. These are considered as indicators of other possible problems. For example, an elevated temperature is usually an indicator of a body infection. If abnormalities are found in any of the key indicators, the doctor will request more detailed information. Over time the medical clinic will create a data file on the health characteristics of the individual.

Similarly, a data file on key soil quality characteristics or indicators are needed so that both the status and changes in soil health can be logged. The quality characteristics and their norms may be different for different taxa, just as they are for human age groups.

Elements of soil quality

The quality of a soil is a composite of its physical, chemical, and biological properties that provide a medium for plant growth, regulate and partition water flow through the environment, and serve as an effective environmental filter. The soil attributes needed to optimize the three functions are similar, but may differ in degree. Soil quality describes how effectively soils:

- accept, hold, and release nutrients and other chemical constituents;
- accept, hold, and release water to plants, streams, and groundwater;
- promote and sustain root growth;
- maintain suitable soil biotic habitat; and
- respond to management and resist degradation.

Many determinations are meaningful measures of the quality of a soil. The measurable soil attributes are often highly correlated, and are inextricably related to the five functions previously mentioned. For example, texture (T) and organic carbon (OC) content are important indicators of the behaviour of a soil with respect to all of the five functions. Table 1 gives a tabulation of some of the more common measures of soil attributes cross-indexed with the five soil elements.

Table 1. Soil attributes and soil quality.

Soil attributes	Elements of soil quality - ability to: Accept, hold and release nutrients	Accept, hold and release water	Promote growth	Provide a suitable soil biotic habitat	Resist degradation
Surface horizons					
organic matter					
total	x	x	x	x	x
labile	x		x	x	x
nutrient supply	x		x	x	x
surface soil texture	x	x	x	x	
surface soil depth	x	x	x		x
surface soil structure		x	x		x
surface soil pH	x	x	x	x	x
surface soil electrolytic conductivity	x		x	x	x
Limiting horizon					
subsoil texture	x	x	x	x	x
subsoil depth	x	x	x		x
subsoil structure		x	x		x
subsoil pH	x		x		x
subsoil electrolytic conductivity	x		x	x	x

Indicators of soil quality

The potential of a soil for crop growth can be evaluated in terms of the environment it provides for root growth and development. The soil rooting environment must be defined in terms of its quantity (volume) and quality. The rooting volume needed for optimum growth depends on the plant species (Taylor and Terrell, 1982), the genetic potential of the plant, and the environmental conditions imposed by the weather and cultural management practices used in the production system.

Chemical constraints to root growth include the presence of inhibitory compounds (e.g. exchangeable Al, salts), nutrient deficiency (either due to the low quantity present or the high fixation capacity of the soil for a particular nutrient), many of which are pH-related. Physical constraints are of two types: those that deal with the suitability of soil to accommodate unobstructed root growth - pore space of sufficient size and continuity for root penetration and

expansion, and the resistance of the soil matrix to deformation (Groenevelt *et al.*, 1984)) - and the capacity of soil for water supply and aeration. Biological constraints include the presence of soil-borne pathogens, diseases, and allelopathic organic compounds. Biological constraints may be more related to past management than to soil development. Constraints can often be alleviated by cultural management practices when they occur at or near the soil surface. Problems in soil productivity arise where inputs are limited, or when undesirable soil attributes occur beyond the ability of the farmer to alleviate them.

The soil is a key element in regulating and partitioning water flow through the landscape. Rainfall in terrestrial ecosystems falls on the soil surface where it either infiltrates the soil or moves across the soil surface into streams or lakes; the condition of the soil surface, determines how this occurs. If it enters the soil it may be stored and later taken up by plants, move into ground waters, or move laterally through the soil later to appear in springs or seeps. Whether water infiltrates or runs off, the soil may release chemicals to the water, or remove chemicals through sorption by the soil or sediments. In all these reactions the soil interacts with the landscape and plant cover. The ability of a soil to act beneficially in its interactions with water in an ecosystem is an important aspect of soil quality.

The soil acts as an effective environmental filter. The disposal or utilization of wastes is an ever-increasing human problem. The soil matrix is the major incubation chamber for the decomposition of organic wastes. Indeed, plant residues decompose in the soil to improve the quality of the soil. Recently, the soil has been looked upon as a possible receptor of many human wastes such as sewage wastes, garbage, and ash from a variety of industrial plants. But soils have varying capacities to encourage decomposition of organic wastes and to adsorb inorganic constituents such as heavy metals. The ability of a soil to be a beneficial receptor of wastes is an important aspect of soil quality.

Table 1. Proposed minimum data set of physical, chemical, and biological indicators for screening the quality or health of soils.

Indicators	Relationship to soil condition and function; Rationale as a priority measurement
	Physical
Texture	Retention and transport of water and chemicals; Modeling use, soil erosion & variability estimate
Depth of soil & rooting	Estimate of productivity potential and erosion; Normalizes landscape & geographic variability
Infiltration & Bulk density	Potential for leaching, productivity, and erosivity; SBD needed to adjust analyses to volumetric basis
Water holding capacity	Related to water retention, transport, and erosivity; Available H_2O; calculate from SBD, texture, & OM
	Chemical
Soil organic matter (OM)	Defines soil fertility, stability, and erosion extent; Use in process models and for site normalization
pH	Defines biological and chemical activity thresholds; Essential to process modeling
Electrical conductivity	Defines plant and microbial activity thresholds; Presently lacking in most process models
Extractable N, P, and K	Plant available nutrients and potential for N loss; Productivity and environmental quality indicators
	Biological
Microbial biomass C & N	Microbial catalytic potential & repository for C & N; Modeling: early warning of manag. Effects on OM
Potentially mineralizable N	Soil productivity and N supplying potential; Process modeling (surrogate indicator of biomass)
Soil respiration	Microbial activity measure (in some cases plants) Process modeling; estimate of biomass activity

(after Doran et al., 1996 and Larson and Pierce, 1994)

Soil Quality is defined as:

The fitness of a specific kind of soil, to function within its capacity and within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

The five soil functions are:

1. Sustaining biological activity, diversity, and productivity;

2. Regulating and partitioning water and solute flow;

3. Filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric depositions;

4. Storing and cycling nutrients and other elements within the earth's biosphere; and

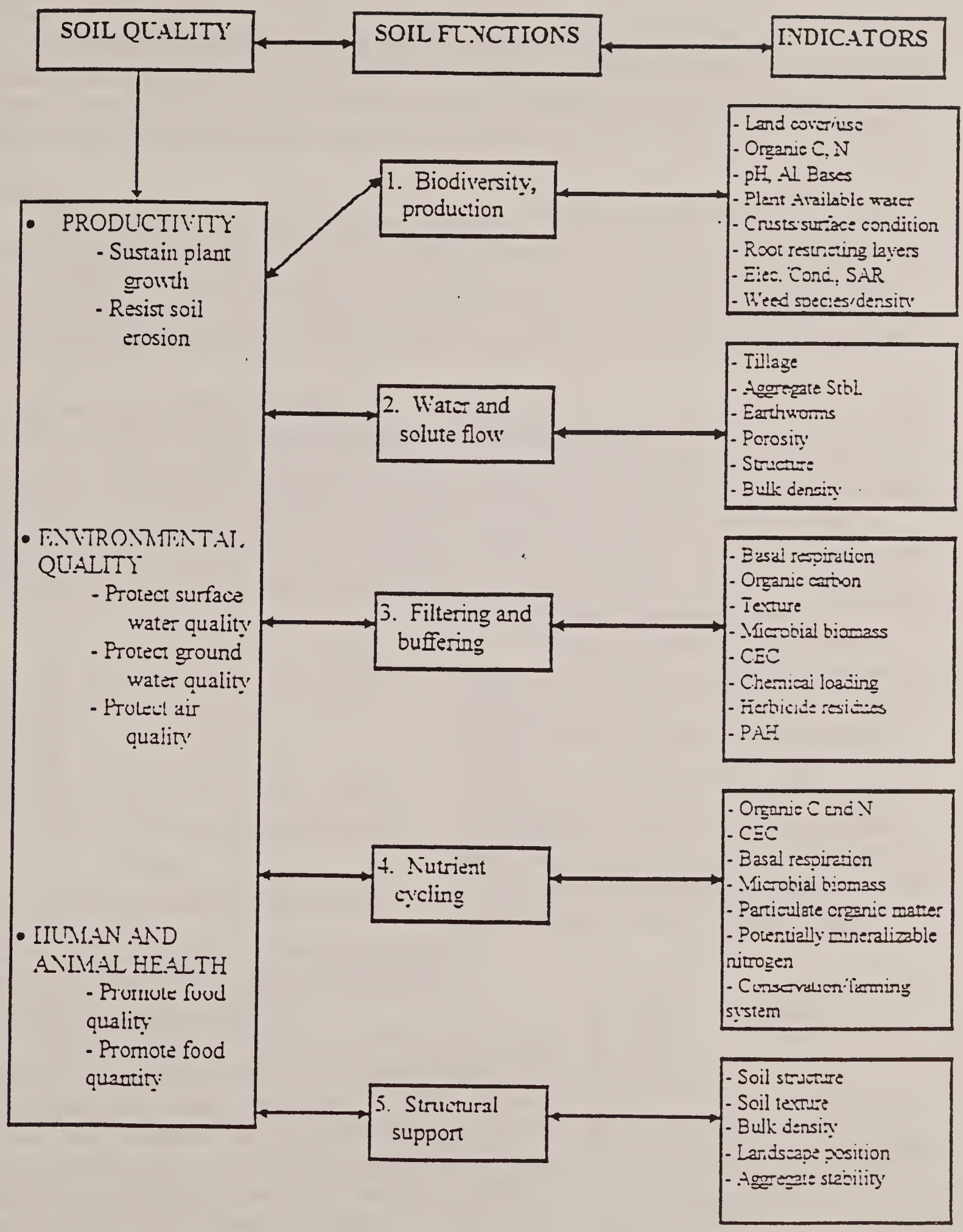
5. Providing support for plant, animal, and human life

The definition of soil quality has two forms:

1. Soil quality is an inherent property of a soil. This inherent property relates to the potential of a soil to function as compared to other soils.

2. Soil quality is the health or condition of a soil. The health or condition of a soil is measured by comparing the current state of an indicator of soil quality to the projected value for a soil functioning at full potential. The health or condition can also be measured over time by following trends in the values of the indicators of soil quality.

Soil Quality Assessment Framework



SOIL QUALITY ASSESSMENT

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[1]National Soil Tilth Laboratory; [2]NRCS

Problem

Soil Quality, which can be simply defined as the "capacity of a soil to function," has been a primary research focus at the National Soil Tilth Laboratory (NSTL) during the past five years. Continued cooperative efforts are needed to develop science-based protocols for quantifying soil quality as a tool for natural resource assessment and evaluation of soil management practices.

Approach

Collaborative research and technology transfer activities conducted in partnership with the Natural Resources Conservation Service (NRCS) Soil Quality Institute personnel and numerous other ARS and University research partners have raised the concept of soil quality from obscurity to an issue that is publicly recognized, scientifically debated, and actively evaluated as a tool for assessing the sustainability of agricultural practices and other land uses.

Findings and Application of Results

Soil quality considers physical, chemical, and biological properties and processes within the living and dynamic soil body. Scientific controversy has surrounded the concept, because soil quality *per se* cannot be measured. It must be assessed by evaluating various qualitative and quantitative indicators. Soil quality evaluation is complicated because assessment must distinguish between inherent or natural differences caused by the basic soil forming factors and the changes occurring in response to land use or management practices. Inherent differences in soil quality are illustrated for two soils in Fig. 1.

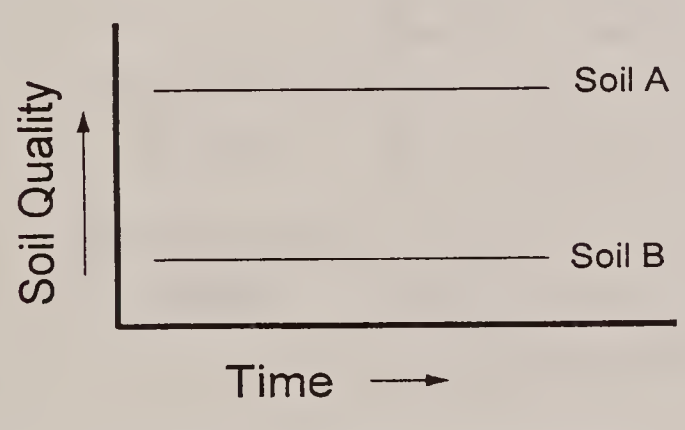


Fig. 1. Inherent soil quality differences.

Physical, chemical, and biological changes occurring in a specific kind of soil reflect dynamic soil quality. This type of assessment, unlike inherent soil quality that reflects the "quality of a soil" formed in response to the natural soil forming factors, examines spatial and temporal variation created by land use, policy, or management decisions. Dynamic soil quality also reflects how the soil resource may be affecting air, water, and other natural resources. The most important use for dynamic soil quality assessments is as a tool for quantitatively evaluating sustainability (Fig. 2).

Current research is focused on identifying the most responsive soil quality indicators, using those indicators to develop soil quality indices, and using the indices as tools for point, field, watershed, and regional assessment. Soil quality assessment was used to evaluate post-Conservation Reserve Management practices and to assess soil quality within four Major Land Resource Areas.

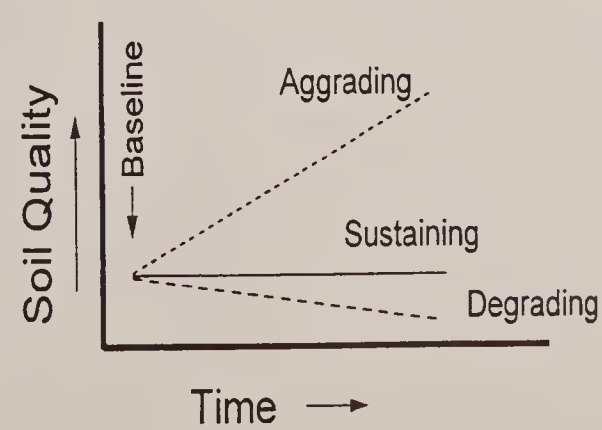
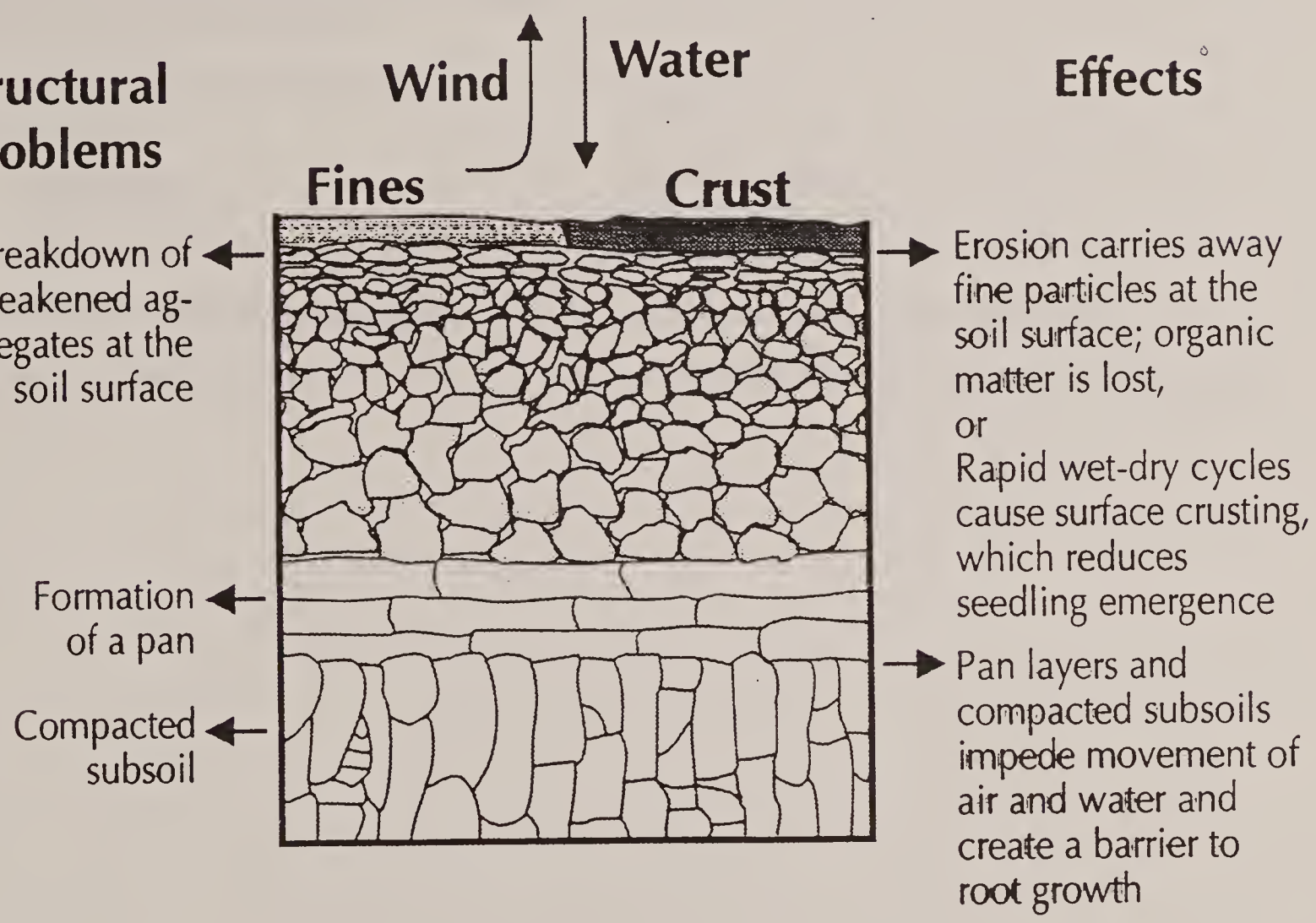


Fig. 2. Dynamic soil quality assessment.

For further information please contact: Doug Karlen; 515-294-3336; dkarlen@nstl.gov

Structural problems throughout the soil profile and effects of degradation



(after Anon. 1994)

Methods For Soil Quality/Health Assessment
Qualitative Methods

Observable Features (Examples)	Possible Causes
Soil crusting; surface sealing	loss of organic matter, aggregation (soil structure), low hydraulic conductivity, high dispersable clays
Rills, gulleys, stones on surface, exposed roots, uneven topsoil, pedstalling	water erosion
Ripple marks, sand dunes, sand cover on soil surface, parallel furrows with notches in heavy soils, and against plant stems, hedges, plant damage, etc.	wind erosion
Salt crust on soil surface; salt-tolerant plants	salinization
Nature of crust:	
• moist & dark	MgC12, Mn22SO4
• fine crystalline	NaCl, Na2SO4
• dark	NaCo3 (black alkali)
Acid tolerant plants, lack of fertilizer response	acidification, chemical degradation of soils
Standing water, ponding of water	poor drainage, compact/hardpan structural deterioration

Methods For Soil Quality/Health Assessment
Quantitative Methods

Soil Attribute	Method of Measurement
Soil depth	Measure depth to a layer that would restrict root growth and water movement. Record the type of layer: bedrock, tillage pan, fragipan, frozen layer, etc.
Water holding capacity (WAC)	Use soil cores of horizons to 100 cm. Measure water retention.
Aggregate stability	Wet-sieving method describe by Keeper and Racine (1986). Measure should be made on samples with same soil water content. (Field method by Jeff Herrick - see soil quality sheet on compaction)
Hydraulic conductivity	Hydraulic conductivity KSAT infiltration rate can be measured by using an adaptation of the Guelph permeameter (Reynolds and Elrick, 1991.) Ideally, infiltration rates should be measured at several times during the season and KSAT at different depths.
Bulk density/soil impedance	Same cores as in WAC can be used for bulk density. Measure soil impedance with cone penetromter. (Field Method - use "shovel slice" note structure upper 30cm.)
Organic matter	Total C and N by dry combustion in a Leco CHN Analyzer other suitable method. Use subsamples of underlaying horizons. (-7.5, 7.5-15 cm) (Field method Dr. Bowan Akron, CO field station color metric)
Cation exchange capacity (CEC)	Exchange Ca, Mg, Na and K
pH	All horizons to 100 cm; preferably use 0.01 MCa C12. If salinity is to be measured, pH of saturated paste may be measured.
Electric conductivity	Use saturated paste as in Rhoades (1982), or 1:2 soil: water suspension.
Exchangeable sodium percentage (ESP)	

6. Soil pH Test

Use the same sample prepared in the EC test to conduct the pH Test. **If you are starting with a fresh soil sample, read the introduction and follow steps 1-3 in the EC test section on preparing your sample.**

Materials needed to measure pH:

- **1/8 cup (29.5 mL) measuring scoop**
- **plastic specimen bottle**
- **calibration buffer solutions**
- **squirt bottle**
- **standardized pH pocket meter**
- **distilled water**

> **?Did You Know?**
> Soil acidification can also be an indication of excessive N fertilizer applications and N leaching loss.

Considerations: If the water content of the soil sample is saturated or very wet, an adjustment should be made so that a 1:1 ratio, on a volume basis, of soil to water is maintained in the soil water mixture when measuring pH (see step 2, Section 5). Also, a small amount of salts diffuse out of the pocket pH meter; therefore, **EC measurements should always be taken first when measuring both EC and pH on the same sample.**

1 Measure and Record pH

- Make sure to calibrate your pH meter periodically (see appendix C for instructions). Before calibrating or taking a reading, place the meter in tap water for about 5 minutes if the meter has not been used in awhile.

- Wait about 10-15 minutes before reading pH (after EC test) to allow soil particles to settle. Insert the pH pocket meter (red & black) into the topmost portion of the solution and turn the meter on; wait until the reading stabilizes (0-30 seconds), and record digital reading on Soil Data worksheet.

2 Rinse Pocket Meter

- Thoroughly rinse the meter with distilled water after use.

- Store the electrode with a few drops of the **pH 7** buffer solution and replace cap. (See appendix C on storage of pH meter)

> **Maintenance Tips**: Check the batteries and calibrate the meters periodically. Be sure to clean the meters thoroughly to keep them working properly.

9. Slake Test

The slake test measures the stability of soil when exposed to rapid wetting. This test is qualitative, and should be measured on air-dried soil fragments or aggregates.

Materials needed for slake test:

- **complete soil stability kit**
- **sampling scoop**
- **distilled water (1L)**

> **?Did You Know?**
> Soil stability serves as a qualitative indicator of soil biological activity, energy flow and nutrient cycling. Binding of soil particles must constantly be renewed by biological processes.

Considerations: The soil should be air dry when performing this test. If the soil is not dry, collect surface fragments as described in the procedure and let them dry. Be careful not to destroy the soil fragments while sampling.

① **Collect surface fragments**

- Carefully remove soil fragments or aggregates from the soil's surface. If there is a surface crust, carefully sample pieces of it. If the soil has been tilled, collect some aggregates (about 1-cm size). Be careful not to shatter the soil fragments or aggregates while sampling.

- Collect 16 separate soil fragments. If there is a surface crust, collect 8 fragments of the crust and 8 fragments from below the crust.

Figure 9.1

② **Fill box with water**

- Remove all sieve baskets from the box.

- Fill the compartments in the box with water. The water should be 2 cm deep and at approximately the same temperature as the soil.

③ **Test soil fragments**

- Place soil fragments in the sieve baskets **(Figure 9.1).**

- Lower one of the sieves into a box compartment filled with water **(Figure 9.2).**

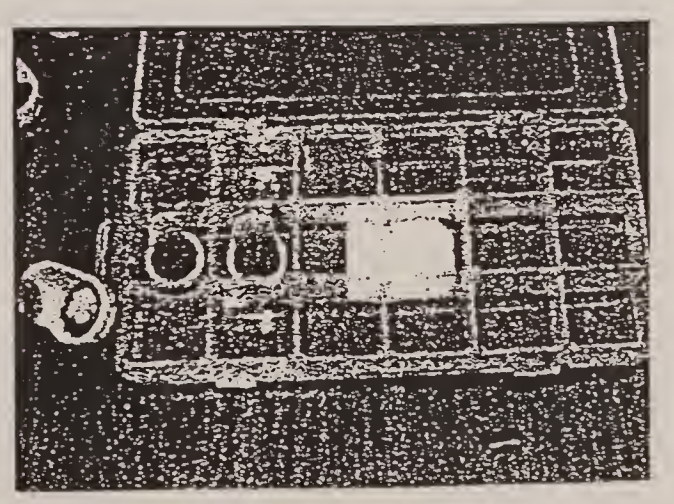


Figure 9.2

4. Observe each fragment for five minutes.

- If the soil fragment does not disintegrate within **five minutes**, raise the basket out of the water, then lower it to the bottom. It should take 1 second for the basket to clear the surface and one second to return to the bottom.

- Repeat immersion for a total of five times.

5. **Record slake test ratings**

- Soil stability is rated according to the time required for the fragment to disintegrate during the five minute immersion (classes 1 - 3) or the proportion of the soil fragment remaining on the mesh after the five extraction-immersion cycles (classes 4 - 6) **see table below.**

- Record the stability ratings for all 16 soil fragments or aggregates on the Soil Data worksheets.

Stability class	Criteria for assignment to stability class (for "Standard Characterization")
0	Soil too unstable to sample (falls through sieve).
1	50 % of structural integrity lost within **5 seconds** of insertion in water.
2	50 % of structural integrity lost **5 - 30 sec.** after insertion.
3	50 % of structural integrity lost **30 - 300 sec.** after insertion.
4	**0 - 25%** of soil remaining on sieve after 5 dipping cycles.
5	**25 - 75%** of soil remaining on sieve after 5 dipping cycles.
6	**75 - 100%** of soil remaining on sieve after 5 dipping cycles.

SOIL QUALITY INFORMATION SHEETS

In a cooperative effort with NRCS and ARS plans are to prepare additional *Soil Quality Information Sheets* tailored for Western rangelands. Refer to Reading the Soil Section for specific topics relevant to rangelands.

Soil Quality Information Sheet

Soil Quality - Introduction

USDA Natural Resources Conservation Service **April 1996**

What is soil?

Soil is a living, dynamic resource that supports plant life. It is made up of different size mineral particles (sand, silt, and clay), organic matter, and numerous species of living organisms. Soil has biological, chemical, and physical properties that are always changing.

What does soil do for us?

Soil provides a physical matrix, chemical environment, and biological setting for water, nutrient, air, and heat exchange for living organisms.

Soil controls the distribution of rainfall or irrigation water to runoff, infiltration, storage, or deep drainage. Its regulation of water flow affects the movement of soluble materials, such as nitrate nitrogen or pesticides.

Soil regulates biological activity and molecular exchanges among solid, liquid, and gaseous phases. This affects nutrient cycling, plant growth, and decomposition of organic materials.

Soil acts as a filter to protect the quality of water, air, and other resources.

Soil provides mechanical support for living organisms and their structures. People and wildlife depend on this function.

What is Soil Quality?

Soil quality is the fitness of a specific kind of soil to function within its surroundings, support plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

How is soil quality important to landowners?

Soil quality enhancement is important to support crop, range, and woodland production and to sustain water supplies. Enhanced soil quality can help to reduce the onsite and offsite costs of soil erosion, improve nutrient use efficiencies, and ensure that the resource is sustained for future use. It is also essential to maintain other resources that depend on the soil, such as water quality, air quality, and wildlife habitat.

How can soil quality be evaluated?

Soil quality and soil health can be evaluated by monitoring several indicators. The type of indicator chosen depends on the soil function and scale (i.e. field, farm, watershed, or region) in which the evaluation is made. For example, an indicator of soil loss by erosion may be the thinning of the surface layer or visual and physical evidence of gullies, small rills, adjacent sediment, etc. Indicators for physical, chemical, and biological conditions can be simple field tests or sophisticated laboratory analyses.

Soil quality indicators may be considered diagnostic tools to assess the health of the soil or else as a cause for concern to the farmer, producer, rancher, woodland manager, or gardener, to stimulate a change in management. Trends in soil health can help in planning and evaluating current land use practices. The information gathered from monitoring soil health can be used to improve conservation recommendations.

How can my awareness of soil quality be applied?

Soil quality can be applied through several natural resource approaches:

-- Data from soil surveys, fertility labs, and field tests can help identify areas where natural soil properties (texture, drainage, etc.) or management related problems currently exist. Once these conditions are identified, corrections can be planned.

-- Areas with potential resource problems can be identified and shown on soil interpretive maps. These fragile areas that can easily be damaged may need more intensive management to prevent damage or be converted to a less demanding land use.

-- After installing conservation practices, trends in soil quality can be tracked to show the success of the practice or the need for other management changes.

What concerns are addressed by soil quality?

Loss of soil material by erosion

Deposition of sediment by wind or floodwaters

Compaction of layers near the surface

Soil aggregation at the surface

Infiltration reduction

Crusting of the soil surface

Nutrient loss or imbalance

Pesticide carryover

Buildup of salts

Change in pH to an unfavorable range

Loss of organic matter

Reduced biological activity and poor residue breakdown

Infestation by weeds or pathogens

Excessive wetness

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Indicators for Soil Quality Evaluation

USDA Natural Resources Conservation Service **April 1996**

What are indicators?

Soil quality indicators are physical, chemical, and biological properties, processes, and characteristics that can be measured to monitor changes in the soil.

The types of indicators that are the most useful depend on the function of soil for which soil quality is being evaluated. These functions include:
- providing a physical, chemical, and biological setting for living organisms;
- regulating and partitioning water flow, storing and cycling nutrients and other elements;
- supporting biological activity and diversity for plant and animal productivity;
- filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials; and
- providing mechanical support for living organisms and their structures.

Why are indicators important?

Soil quality indicators are important to:
- focus conservation efforts on maintaining and improving the condition of the soil;
- evaluate soil management practices and techniques;
- relate soil quality to that of other resources;
- collect the necessary information to determine trends;
- determine trends in the health of the Nation's soils;
- guide land manager decisions.

What are some indicators?

Indicators of soil quality can be categorized into four general groups: visual, physical, chemical, and biological.

Visual indicators may be obtained from observation or photographic interpretation. Exposure of subsoil, change in soil color, ephemeral gullies, ponding, runoff, plant response, weed species, blowing soil, and deposition are only a few examples of potential locally determined indicators. Visual evidence can be a clear indication that soil quality is threatened or changing.

Physical indicators are related to the arrangement of solid particles and pores. Examples include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or movement of water within the soil profile.

Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed for plant growth and development. The soil's chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants, and some physical conditions, such as the tendency for crust to form.

Biological indicators include measurements of micro- and macro-organisms, their activity, or byproducts. Earthworm, nematode, or termite populations have been suggested for use in some parts of the country. Respiration rate can be used to detect microbial activity, specifically microbial decomposition of organic matter in the soil. Ergosterol, a fungal byproduct, has been used to measure the activity of organisms that play an important role in the formation and stability of soil aggregates. Measurement of decomposition rates of plant residue in bags or measurements of weed seed numbers, or pathogen populations can also serve as biological indicators of soil quality.

How are indicators selected?

Soil quality is estimated by observing or measuring several different properties or processes. No single property can be used as an index of soil quality.

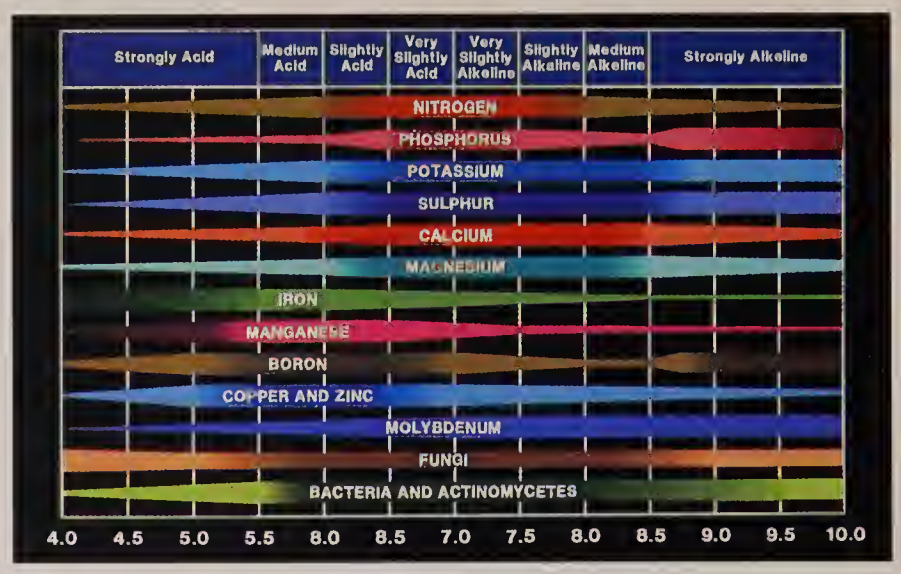
The selection of indicators should be based on:
- the land use;
- the relationship between an indicator and the soil function being assessed;
- the ease and reliability of the measurement;
- variation between sampling times and variation across the sampling area;
- the sensitivity of the measurement to changes in soil management;
- compatibility with routine sampling and monitoring;
- the skills required for use and interpretation.

When and where to measure?

The optimum time and location for observing or sampling soil quality indicators depends on the function for which the assessment is being made. The frequency of measurement also varies according to climate and land use.

Soil variation across a field, pasture, forest, or rangeland can greatly affect the choice of indicators. Depending on the function, such factors as the landscape unit, soil map unit, or crop growth stage may be critical. Wheel tracks can dramatically affect many properties measured for plant productivity. Management history and current inputs should also be recorded to ensure a valid interpretation of the information.

Monitoring soil quality should be directed primarily toward the detection of trend changes that are measurable over a 1- to 10-year period. The detected changes must be real, but at the same time they must change rapidly enough so that land managers can correct problems before undesired and perhaps irreversible loss of soil quality occurs.



Soil reaction influence on availability of plant nutrients.

What does the value mean?

Interpreting indicator measurements to separate soil quality trends from periodic or random changes is currently providing a major challenge for researchers and soil managers. Soils and their indicator values vary because of differences in parent material, climatic condition, topographic or landscape position, soil organisms, and type of vegetation. For example, cationexchange capacity may relate to organic matter, but it may also relate to the kind and amount of clay.

Establishing acceptable ranges, examining trends and rates of change over time, and including estimates of the variance associated with the measurements are important in interpreting indicators. Changes need to be evaluated as a group, with a change in any one indicator being evaluated only in relation to changes in others. Evaluations before and after, or with and without intervention, are also needed to develop appropriate and meaningful relationships for various kinds of soils and the functions that are expected of them.

The overall goal should be to maintain or improve soil quality without adversely affecting other resources.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Indicators: Organic Matter

USDA Natural Resources Conservation Service **April 1996**

What is soil organic matter?

Soil organic matter is that fraction of the soil composed of anything that once lived. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Well-decomposed organic matter forms *humus*, a dark brown, porous, spongy material that has a pleasant, earthy smell. In most soils, the organic matter accounts for less than about 5% of the volume.

What does organic matter do?

Organic matter is an essential component of soils because it:

- provides a carbon and energy source for soil microbes;
- stabilizes and holds soil particles together, thus reducing the hazard of erosion;
- aids the growth of crops by improving the soil's ability to store and transmit air and water;
- stores and supplies such nutrients as nitrogen, phosphorus, and sulfur, which are needed for the growth of plants and soil organisms;
- retains nutrients by providing cation-exchange and anion-exchange capacities;
- maintains soil in an uncompacted condition with lower bulk density;
- makes soil more friable, less sticky, and easier to work;
- retains carbon from the atmosphere and other sources;
- reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants.

Soil organic matter also improves tilth in the surface horizons, reduces crusting, increases the rate of water infiltration, reduces runoff, and facilitates penetration of plant roots.

Where does it come from?

Plants produce organic compounds by using the energy of sunlight to combine carbon dioxide from the atmosphere with water from the soil. Soil organic matter is created by the cycling of these organic compounds in plants, animals, and microorganisms into the soil.

What happens to soil organic matter?

Soil organic matter can be lost through erosion. This process selectively detaches and transports particles on the soil surface that have the highest content of organic matter.

Soil organic matter is also utilized by soil microorganisms as energy and nutrients to support their own life processes. Some of the material is incorporated into the microbes, but most is released as carbon dioxide and water. Some nitrogen is released in gaseous form, but some is retained, along with most of the phosphorus and sulfur.

When soils are tilled, organic matter is decomposed faster because of changes in water, aeration, and temperature conditions. The amount of organic matter lost after clearing a wooded area or tilling native grassland varies according to the kind of soil, but most organic matter is lost within the first 10 years.

Rates of decomposition are very low at temperatures below 38 ^{o}F (4 ^{o}C) but rise steadily with increasing

temperature to at least 102 °F (40 °C) and with water content until air becomes limiting. Losses are higher with aerobic decomposition (with oxygen) than with anaerobic decomposition (in excessively wet soils). Available nitrogen also promotes organic matter decomposition.

What controls the amount?

The amount of soil organic matter is controlled by a balance between additions of plant and animal materials and losses by decomposition. Both additions and losses are very strongly controlled by management activities.

The amount of water available for plant growth is the primary factor controlling the production of plant materials. Other major controls are air temperature and soil fertility. Salinity and chemical toxicities can also limit the production of plant biomass. Other controls are the intensity of sunlight, the content of carbon dioxide in the atmosphere, and relative humidity.

The proportion of the total plant biomass that reaches the soil as a source of organic matter depends largely on the amounts consumed by mammals and insects, destroyed by fire, or produced and harvested for human use.

Practices decreasing soil organic matter include those that:

1. **Decrease the production of plant materials by**
   - replacing perennial vegetation with short-season vegetation,
   - replacing mixed vegetation with monoculture crops,
   - introducing more aggressive but less productive species,
   - using cultivars with high harvest indices,
   - increasing the use of bare fallow.

2. **Decrease the supply of organic materials by**
   - burning forest, range, or crop residue,
   - grazing,
   - removing plant products.

3. **Increase decomposition by**
   - tillage,
   - drainage,
   - fertilization (especially with nitrogen).

Practices increasing soil organic matter include those that:

1. **Increase the production of plant materials by**
   - irrigation,
   - fertilization to increase plant biomass production,
   - use of cover crops
   - improved vegetative stands,
   - introduction of plants that produce more biomass,
   - reforestation,
   - restoration of grasslands.

2. **Increase supply of organic materials by**
   - protecting from fire,
   - using forage by grazing rather than by harvesting,
   - controlling insects and rodents,
   - applying animal manure or other carbon-rich wastes,
   - applying plant materials from other areas.

3. **Decrease decomposition by**
   - reducing or eliminating tillage,
   - keeping the soil saturated with water (although this may cause other problems),
   - keeping the soil cool with vegetative cover.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Animal waste photo courtesy University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources

Soil Quality Information Sheet

Soil Quality Indicators: Aggregate Stability

USDA Natural Resources Conservation Service April 1996

What are soil aggregates?

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The space between the aggregates provide pore space for retention and exchange of air and water.

What is aggregate stability?

Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied.

Aggregate stability is not the same as *dry aggregate stability*, which is used for wind erosion prediction. The latter term is a size evaluation.

Why is aggregate stability important?

Aggregation affects erosion, movement of water, and plant root growth. Desirable aggregates are stable against rainfall and water movement. Aggregates that break down in water or fall apart when struck by raindrops release individual soil particles that can seal the soil surface and clog pores. This breakdown creates crusts that close pores and other pathways for water and air entry into a soil and also restrict emergence of seedlings from a soil.

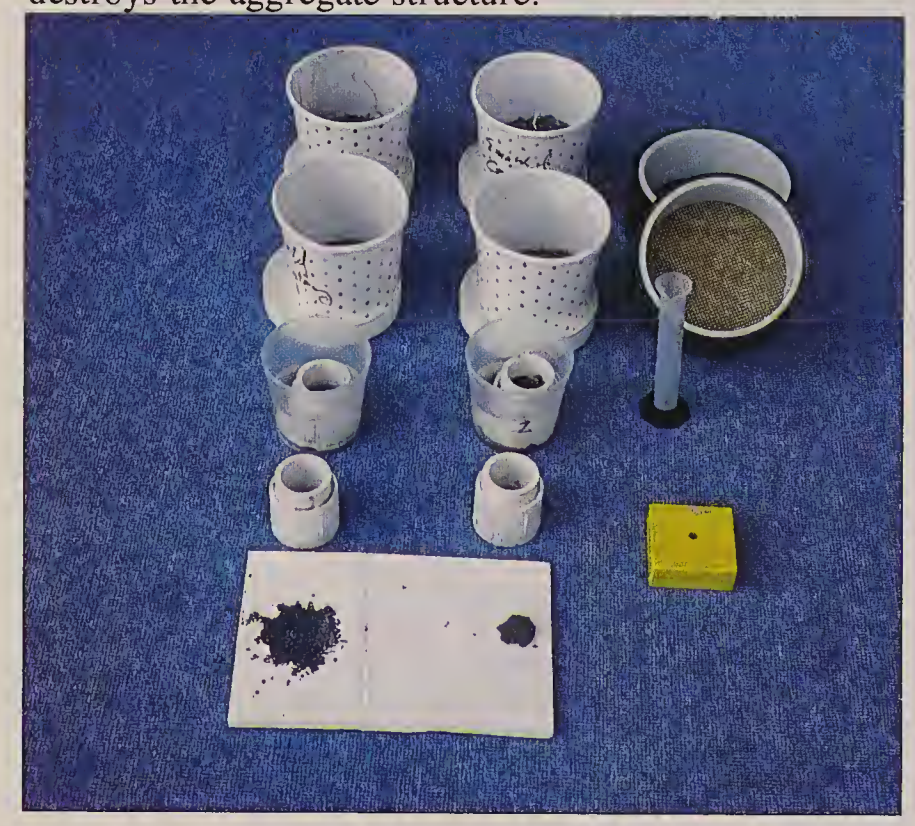
Optimum conditions have a large range in pore size distribution. This includes large pores between the aggregates and smaller pores within the aggregates. The pore space between aggregates is essential for water and air entry and exchange. This pore space provides zones of weakness through which plant roots can grow. If the soil mass has a low bulk density or large pore spaces, aggregation is less important. For example, sandy soils have low aggregation, but roots and water can move readily.

How is aggregate stability measured?

Numerous methods measure aggregate stability. The standard method of the NRCS Soil Survey Laboratory can be used in a field office or in a simple laboratory. This procedure involves repeated agitation of the aggregates in distilled water.

An alternative procedure described here does not require weighing. The measurements are made on air-dry soil that has passed through a sieve with 2-millimeter mesh and retained by a sieve with a 1-millimeter mesh. A quantity of these 2-1 millimeter aggregates is placed in a small open container with a fine screen at the bottom. This container is placed in distilled water. After a period of time, the container is removed from the water and its contents are allowed to dry. The content is then removed and visually examined for the breakdown from the original aggregate size. Those materials that have the least change from the original aggregates have the greatest aggregate stability.

Soils that have a high percentage of silt often show lower aggregate stability if measured air-dry than the field behavior would suggest, because water entry destroys the aggregate structure.



What influences aggregate stability?

The stability of aggregates is affected by soil texture, the predominant type of clay, extractable iron, and extractable cations, the amount and type of organic matter present, and the type and size of the microbial population.

Some clays expand like an accordion as they absorb water. Expansion and contraction of clay particles can shift and crack the soil mass and create or break apart aggregates.

Calcium ions associated with clay generally promote aggregation, whereas sodium ions promote dispersion.

Soils with over about five percent iron oxides, expressed as elemental iron, tend to have greater aggregate stability.

Soils that have a high content of organic matter have greater aggregate stability. Additions of organic matter increase aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products or mycelia have formed.

Soil microorganisms produce many different kinds of organic compounds, some of which help to hold the aggregates together. The type and species of microorganisms are important. Fungal mycelial growth binds soil particles together more effectively than smaller organisms, such as bacteria.

Aggregate stability declines rapidly in soil planted to a clean-tilled crop. It increases while the soil is in sod and crops, such as alfalfa.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Indicators: Soil Crusts

USDA Natural Resources Conservation Service April 1996

What are soil crusts?

Soil crusts are relatively thin, somewhat continuous layers of the soil surface that often restrict water movement, air entry, and seedling emergence from the soil. They generally are less than 2 inches thick and are massive.

Crusts are created by the breakdown of structural units by flowing water, or raindrops, or through freeze-thaw action. Soil crusts are generally only a temporary condition. Typically, the soil immediately below the surface layer is loose.

Why are soil crusts a concern?

Crusts reduce infiltration and increase runoff. Rainfall and sprinkler irrigation water impart a large amount of impact energy onto the soil surface. If the soil is not protected by a cover of growing plants, crop residue or other material, and if soil aggregates are weak, the energy can cause a soil crust to form.

If a crust forms, individual soil particles fill the pore space near the surface and prevent the water from entering (infiltrating) the soil. If the infiltration is limited, water accumulates and flows down slope, causing movement of soil particles. Thus water erosion is initiated.

Crusts restrict seedling emergence. The physical emergence of seedlings through a soil crust depends on the:

- thickness of the crust,
- strength of the crust,
- size of the broken crust pieces,
- water content, and
- type of plant species. Non-grass plant species, such as soybeans or alfalfa, exert less pressure under identical conditions than grasses such as corn.

Crusts reduce oxygen diffusion to seedlings. Seed germination depends on the diffusion of oxygen from the air through the soil. If soil crusts are wet, oxygen diffusion is reduced as much as 50 percent.

Crusts reduce surface water evaporation. The reflectance of a crusted surface is higher than that for an uncrusted surface. Higher reflectance results in less absorption of energy from the sun. This results in a cooler soil surface and decreases the rate of evaporation.

Crusts decrease water loss because less of their surface area is exposed to the air than a tilled soil. When crusts become dry, they become barriers to evaporation by retarding capillary movement of water to the soil surface.

Crusts affect wind erosion. Crusts increase wind erosion in those soils that have an appreciable amount of sand. Rainfall produces clean sand grains that are not attached to the soil surface. These clean sand grains are subject to movement by air along the smooth surface of the crust. The sand breaks down the crust as it moves across the soil surface. Cultivation to break the crust and increase the surface roughness reduces wind erosion on sandy soils.

For soils that have a small amount of sand, crusts protect the soil surface and generally decrease the hazard of wind erosion.

How do crusts form?

Soil crusts and associated cracks form by raindrop impact or freeze-thaw processes.

Raindrop impact breaks soil aggregates, moves clay downward a short distance leaving a concentration of sand and silt particles on the soil surface.

Raindrop-impact crusts break down to a granular condition in many soils that have a high shrink-swell potential and experience frequent wetting and drying cycles.

Freeze-thaw crusts are formed by the puddling effect as ice forms, melts, and reforms. The temperature and water regimes and parent material control freeze-thaw crust formation. These crusts are generally 3/8- to 5/8-inch thick, compared to 1/4-inch commonly for raindrop-impact crusts.

The size and behavior on wetting of cracks associated with raindrop-impact and freeze-thaw crust differ. Both extend to the base of the crust. The cracks in raindrop-impact crust are 1/4 inch wide. They close on wetting and hence are ineffective in increasing infiltration. The cracks in freeze-thaw crust are 1/4- to 3/4-inch wide. They do not close on wetting and hence increase infiltration.

How are soil crusts measured?

Soil crusts are characterized by their thickness and strength (air dry rupture resistance). Crust air dry rupture resistance can be measured by taking a dry piece about 1/2 inch on edge and applying a force on the edge until the crust breaks. In general, more force is required for crusts that are thick and have a high clay content. Other means of measurement, such as a penetrometer, may be used.

How can the problem be corrected?

- Maintain plant cover or crop residues on the soil surface to reduce the impact of raindrops.

- Adopt management practices that increase aggregate stability.

- Use practices that increase soil organic matter content or reduce concentrations of sodium ions.

- Use a rotary hoe or row cultivator to shatter crusts and thus increase seedling emergence and weed control.

- Employ sprinkler water to reduce restriction of seedling emergence.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Soil crust photo courtesy of University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources.

Soil Quality Information Sheet

Soil Quality Resource Concerns: Soil Erosion

USDA Natural Resources Conservation Service **April 1996**

What is erosion?

Wind or water erosion is the physical wearing of the earth's surface. Surface soil material is removed in the process.

Why should we be concerned?

Erosion removes topsoil, reduces levels of soil organic matter, and contributes to the breakdown of soil structure. This creates a less favorable environment for plant growth.

In soils that have restrictions to root growth, erosion decreases rooting depth, which decreases the amount of water, air, and nutrients available to plants.

Erosion removes surface soil, which often has the highest biological activity and greatest amount of soil organic matter. This causes a loss in nutrients and often creates a less favorable environment for plant growth.

Nutrients removed by erosion are no longer available to support plant growth onsite, but can accumulate in water where such problems as algal blooms and lake eutrophication may occur.

Deposition of eroded materials can obstruct roadways and fill drainage channels. Sediment can damage fish habitat and degrade water quality in streams, rivers, and lakes.

Blowing dust can affect human health and create public safety hazards.

What are some signs of erosion?

Wind erosion:

- dust clouds,
- soil accumulation along fencelines or snowbanks,
- a drifted appearance of the soil surface.

Water erosion:

- small rills and channels on the soil surface,
- soil deposited at the base of slopes,
- sediment in streams, lakes, and reservoirs,
- pedestals of soil supporting pebbles and plant material.

Water erosion is most obvious on steep, convex landscape positions. However, erosion is not always readily visible on cropland because farming operations may cover up its signs. Loss of only 1/32 of an inch can represent a 5 ton per acre soil loss.

Long-term soil erosion results in:

- persistent and large gullies,
- exposure of lighter colored subsoil at the surface,
- poorer plant growth.

How can soil erosion be measured?

Visual, physical, chemical, and biological indicators can be used to estimate soil surface stability or loss.

Visual indicators

- comparisons of aerial photographs taken over time,
- presence of moss and algae (crypotogams) crusts in desert or arid soils,
- changes in soil horizon thickness,
- deposition of soil at field boundaries.

Physical indicators

- measurements of aggregate stability,
- increasing depth of channels and gullies.

Chemical indicators

- decreases in soil organic matter content,
- increases in calcium carbonate content at the surface, provided greater content exists in subsurface layers,
- changes in cation-exchange capacity (CEC).

Biological indicators

- decreased microbial biomass,
- lower rate of respiration,
- slower decomposition of plant residues.

What causes the problem?

Water erosion

- lack of protection against raindrop impact,
- decreased aggregate stability,
- long and steep slopes,
- intense rainfall or irrigation events when plant or residue cover is at a minimum,
- decreased infiltration by compaction or other means.

Mechanical erosion

- removal by harvest of root crops,
- tillage and cultivation practices that move soil downslope.

Wind erosion

- exposed surface soil during critical periods of the year,
- occurrence of wind velocities that are sufficient to lift individual soil particles,
- long, unsheltered, smooth soil surfaces.

How can soil erosion be avoided?

Soil erosion can be avoided by:

- maintaining a protective cover on the soil,
- creating a barrier to the erosive agent,
- modifying the landscape to control runoff amounts and rates.

Specific practices to avoid water erosion:

- growing forage crops in rotation or as permanent cover,
- growing winter cover crops
- interseeding,
- protecting the surface with crop residue,
- shortening the length and steepness of slopes,
- increasing water infiltration rates,
- improving aggregate stability.

Specific practices to avoid wind erosion:

- maintaining a cover of plants or residue,
- planting shelterbelts,
- stripcropping,
- increase surface roughness,
- cultivating on the contour,
- maintaining soil aggregates at a size less likely to be carried by wind.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Resource Concerns: Compaction

USDA Natural Resources Conservation Service April 1996

What is compaction?

Soil compaction occurs when soil particles are pressed together, reducing the pore space between them. This increases the weight of solids per unit volume of soil (bulk density). Soil compaction occurs in response to pressure (weight per unit area) exerted by field machinery or animals. The risk for compaction is greatest when soils are wet.

Why is compaction a problem?

Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. It decreases pore size, increases the proportion of water-filled pore space at field moisture, and decreases soil temperature. This affects the activity of soil organisms by decreasing the rate of decomposition of soil organic matter and subsequent release of nutrients.

Compaction decreases infiltration and thus increases runoff and the hazard of water erosion.

How can compacted soils be identified?

- platy or weak structure, or a massive condition,
- greater penetration resistance,
- higher bulk density,
- restricted plant rooting,
- flattened, turned, or stubby plant roots.

The significance of bulk density depends on the soil texture. Rough guidelines for the minimum bulk density at which a root restricting condition will occur for various soil textures are (g/cc stands for grams per cubic centimeter):

Texture	Bulk Density (g/cc)
Coarse, medium, and fine sand and loamy sands other than loamy very fine sand	1.80
Very fine sand, loamy very fine sand	1.77
Sandy loams	1.75
Loam, sandy clay loam	1.70
Clay loam	1.65
Sandy clay	1.60
Silt, silt loam	1.55
Silty clay loam	1.50
Silty clay	1.45
Clay	1.40

What causes soil compaction?

Soil compaction is caused by tilling, harvesting, or grazing when the soils are wet.

Soil water content influences compaction. A dry soil is much more resistant to compaction than a moist or wet soil.

Other factors affecting compaction include the texture, pressure exerted, composition (texture, organic matter, plus clay content and type), and the number of passes by vehicle traffic and machinery. Sandy loam, loam, and sandy clay loam soils compact more easily than silt, silt loam, silty clay loam, silty clay, or clay soils.

Compaction may extend to 20 inches. Deep compaction affects smaller areas than shallow compaction, but it persists because shrinking and swelling and freezing and thawing affect it less. Machinery that has axle loads of more than 10 tons may cause compaction below 12 inches. Grazing by large animals can cause compaction because their hooves have a relatively small area and therefore exert a high pressure.

How long will compaction last?

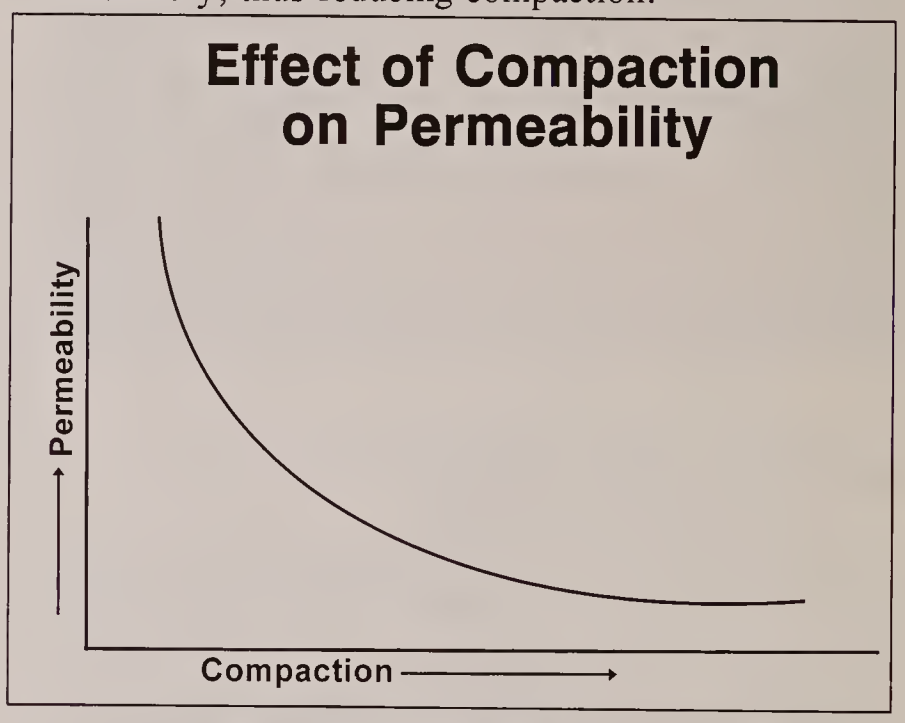
The persistence of soil compaction is determined by the depth at which it occurs, the shrink-swell potential of the soil, and the climate. As the depth increases, the more persistent the condition. The type and percentage of clay determine the shrink-swell potential. The greater the shrink-swell potential and number of wet/dry cycles, the lower is the duration of compaction at a particular depth. Freeze/thaw cycles also help decrease near-surface compaction.

How do organic matter and compaction interact?

Soil organic matter promotes aggregation of soil particles. This increases porosity and reduces bulk density (i.e., compaction). It also increases permeability and may increase plant available water.

Addition of manure, compost, or other organic materials including newspaper, woodchips, and municipal sludge can improve soil structure, helping to resist compaction.

Thick layers of forest litter reduce the impact of machinery, thus reducing compaction.



How can compaction be reduced?

- Reduce the number of trips across the area.
- Till or harvest when the soils are not wet.
- Reduce the pressure of equipment.
- Maintain or increase organic matter in the soil.
- Harvest timber on frozen soil or snow.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

Soil Quality Information Sheet

Soil Quality Resource Concerns: Sediment Deposition on Cropland

USDA Natural Resources Conservation Service **April 1996**

What is sediment deposition?

Sediment is solid material that is or has been transported from its site of origin by air, water, gravity, or ice to a field or low landscape position. Deposition occurs when the amount of sediment becomes greater than the carrying capacity of the force that is moving it.

How is soil quality affected?

Sediment can either improve or degrade the soils upon which it is deposited. The impact of sediment deposition depends on the characteristics of the original soil, rate of deposition, type of material, and depth of deposition.

Fine-grained soil particles deposited on sandy soils generally improve soil quality, but if coarser material is deposited on fine-textured soils there is a more delicate balance. Soil quality may improve over a short period, but coarser material generally results in degraded soil structure and physical characteristics and decreased fertility.

Deposits of infertile sand on a highly productive silt loam that is high in organic matter and nutrients can significantly decrease the quality of the silt loam. However, soil quality would change little if similar deposits occurred on a sandy soil that had a low content of organic matter, and low levels of nitrogen, phosphorus, and potash.

The rate of deposition also affects soil quality. If an inch of sand is deposited on a fertile soil every year for 16 years, the effects would be much less than if eight inches of sand were deposited in one year. Incremental deposits become incorporated with the surface layer and improve with organic matter accumulation.

How is sediment deposition identified?

Modern deposits of sediment have different physical characteristics than the older, buried soils upon which they were deposited. The buried soil is generally darker and more uniform in color. The sediment deposits are generally less dense, with a wider range in grain sizes. Sediment deposits often show distinct stratification or layering.

What can be done about sediment deposition?

Management response to sediment deposition is generally determined by the depth of deposition and the quality of the underlying soil. Generally, as the depth of sediment deposition increases, less mixing is possible.

Potential management practices include the one-time use of:

- **moldboard plowing,** which generally turns 6 to 8 inches of soil over but causes a minimum amount of mixing between the surface and subsurface layers.

- **chisel plowing,** which causes a greater degree of mixing but generally disturbs the soil to a shallower depth of only 4 to 6 inches.

- **deep chiseling,** which disturbs the soil to the greatest depth (12 to 24 inches) but generally results in a minimal amount of mixing.

The best method for addressing sedimentation is **prevention,** since soil quality generally decreases as the depth of sediment deposition increases.

Prevent soil erosion in upstream landscape positions by maintaining plant or crop residue cover, high infiltration rates, and minimal runoff.

Conservation practices on upstream watersheds reduce the risk of high volume flooding and damaging sediment deposition. Dikes, levees, and intercepting channels are used to provide local protection from some flooding and sediment deposition.

Relationships between the depth and type of sediment deposit and damage to soils on flood plains relative to crop yield are shown in the following table. An estimate of the amount of recovery and the length of time required are made with the assumption that the flooding was a one-time event and would not reoccur.

	Depth and Texture	Damage Pct	Recovery Period Yrs	Damage Remaining After Recovery Pct
4 - 8"	fine sand and silt coarse sand and silt	20	5	0
4 - 8"	medium sand coarse sand	40	10	10
8 - 12"	fine sand coarse sand	40	10	10
12 - 14"	coarse sand	60	20	30
12 - 24"	coarse sand and gravel	90	30	50

(from Technical Release No. 17, Geologic Investigations for Watershed Planning, USDA, SCS, 1966)

(Prepared by National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA)

Soil Quality Information Sheet

Soil Quality Resource Concerns: Soil Biodiversity

USDA Natural Resources Conservation Service January 1998

What is soil biodiversity?

Soil biodiversity reflects the mix of living organisms in the soil. These organisms interact with one another and with plants and small animals forming a web of biological activity.

Soil is by far the most biologically diverse part of Earth. The soil food web includes beetles, springtails, mites, worms, spiders, ants, nematodes, fungi, bacteria, and other organisms. These organisms improve the entry and storage of water, resistance to erosion, plant nutrition, and break down of organic matter. A wide variety of organisms provides checks and balances to the soil food web through population control, mobility, and survival from season to season.

What are the benefits of soil organisms?

Residue decomposition
Soil organisms decompose plant residue. Each organism in the soil plays an important role. The larger organisms in the soil shred dead leaves and stems. This stimulates cycling of nutrients. The larger soil fauna include earthworms, termites, pseudoscorpions, microspiders, centipedes, ants, beetles, mites, and springtails.

When mixing the soil, the large organisms bring material to smaller organisms. The large organisms also carry smaller organisms within their systems or as "hitchhikers" on their bodies.

Small organisms feed on the by-products of the larger organisms. Still smaller organisms feed on the products of these organisms. The cycle repeats itself several times with some of the larger organisms feeding on smaller organisms.

Some larger organisms have a life span of two or more years. Smaller organisms generally die more quickly, but they also multiply rapidly when conditions are favorable. The food web is therefore quick to respond when food sources are available and moisture and temperature conditions are good.

Infiltration and storage of water
Channels and aggregates formed by soil organisms improve the entry and storage of water. Organisms mix the porous and fluffy organic material with mineral matter as they move through the soil. This mixing action provides organic matter to non-burrowing fauna and creates pockets and pores for the movement and storage of water. Fungal hyphae bind soil particles together and slime from bacteria help hold clay particles together. The water-stable aggregates formed by these processes are more resistant to erosion than individual soil particles. The aggregates increase the amount of large pore space which increases the rate of water infiltration. This reduces runoff and water erosion and increases soil moisture for plant growth.

Nutrient cycling
Soil organisms play a key role in nutrient cycling. Fungi, often the most extensive living organisms in the soil, produce fungal hyphae. Hyphae frequently appear like fine white entangled thread in the soil. Some fungal hyphae (mycorrhizal fungi) help plants extract nutrients from the soil. They supply nutrients to the plant while obtaining carbon in exchange and thus extend the root system. Root exudates also provide food for fungi, bacteria, and nematodes.

When fungi and bacteria are eaten by various mites, nematodes, amoebas, flagellates, or ciliates, nitrogen is released to the soil as ammonium. Decomposition by soil organisms converts nitrogen from organic forms in decaying plant residues and organisms to inorganic forms which plants can use.

Management considerations

Cultivation

The effects of cultivation depend on the depth and frequency of the cultivation. Tilling to greater depths and more frequent cultivations have an increased negative impact on all soil organisms. No-till, ridge tillage, and strip tillage are the most compatible tillage systems that physically maintain soil organism habitat and biological diversity in crop production.

Compaction

Soil compaction reduces the larger pores and pathways, thus reducing the amount of suitable habitat for soil organisms. It also can move the soil toward anaerobic conditions, which change the types and distribution of soil organisms in the food web. Gaps in the food web induce nutrient deficiencies to plants and reduce root growth.

Pest control

Pesticides that kill insects also kill the organisms carried by them. If important organisms die, consider replacing them. Plant-damaging organisms usually increase when beneficial soil organisms decrease. Beneficial predator organisms serve to check and balance various pest species.

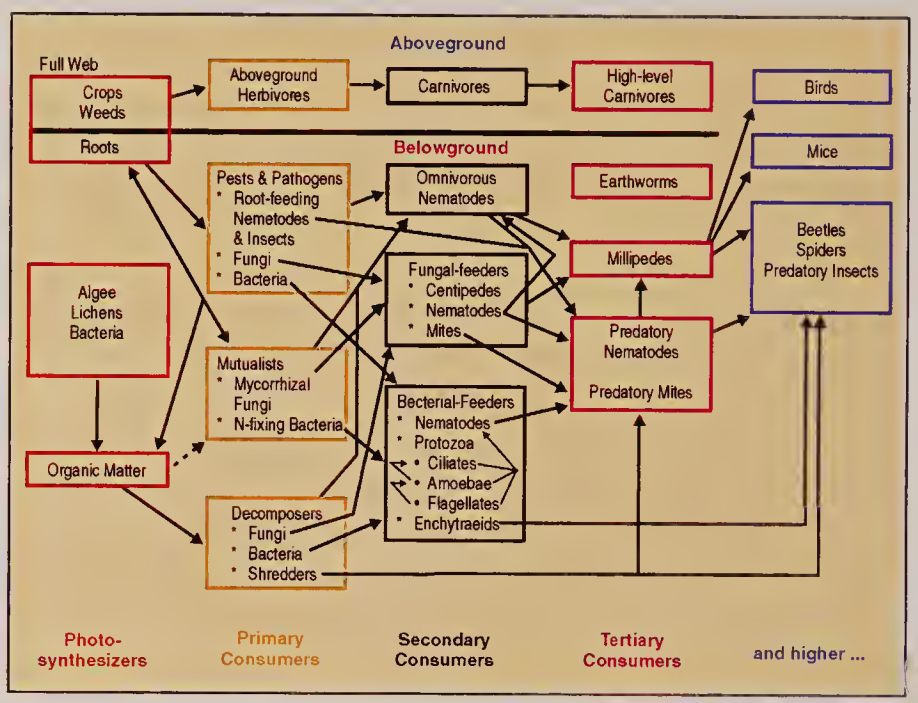
Herbicides and foliar insecticides applied at recommended rates have a small impact on soil organisms. Fungicides and fumigants have a much greater impact on soil organisms.

Fertility

Fertility and nutrient balances in the soil promote biological diversity. Typically, carbon is the limiting resource to biological activity. Plant residue, compost, and manure provide carbon. Compost also provides a mix of organisms, so the compost should be matched to the cropping system.

Cover crops and crop rotations

The type of crops that are used as cover or in crop rotations can affect the mix of organisms that are in the soil. They can assist in the control of plant pests or serve as hosts to increase the number of pests. Different species and cultivars of crops may have different effects on pests. However, the organisms and their relation to the crop are presently not clearly understood.



Crop residue management

Mixing crop residue into the soil generally destroys fungal hyphae and favors the growth of bacteria. Since bacteria hold less carbon than fungi, mixing often releases a large amount of carbon as carbon dioxide (CO_2). The net result is loss of organic matter from the soil.

When crop residue is left on the soil surface, primary decomposition is by arthropod shredding and fungal decomposition. The hyphae of fungi can extend from below the soil surface to the surface litter and connect the nitrogen in the soil to the carbon at the surface. Fungi maintain a high C:N ratio and hold carbon in the soil. The net result is toward building the carbon and organic matter level of the soil. In cropping systems that return residue, macro-organisms are extremely important. Manage the soil to increase their diversity and numbers.

(Prepared by the National Soil Survey Center, NRCS, USDA in cooperation with the Soil Quality Institute, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Information Sheet

Soil Quality Resource Concerns:

Available Water Capacity

USDA Natural Resources Conservation Service January 1998

What is available water capacity?

Available water capacity is the amount of water that a soil can store that is available for use by plants.

It is the water held between field capacity and the wilting point adjusted downward for rock fragments and for salts in solution. Field capacity is the water retained in a freely drained soil about 2 days after thorough wetting. The wilting point is the water content at which sunflower seedlings wilt irreversibly.

Why be concerned?

In areas where drizzle falls daily and supplies the soils with as much or more water than is removed by plants, available water capacity is of little importance. In areas where plants remove more water than the amount supplied by precipitation, the amount of available water that the soil can supply may be critical. This water is necessary to sustain the plants between rainfall events or periods of irrigation. The soil effectively buffers the plant root environment against periods of water deficit.

How is available water expressed?

Available water is expressed as a volume fraction (0.20), as a percentage (20%), or as an amount (in inches). An example of a volume fraction is water in inches per inch of soil. If a soil has an available water fraction of 0.20, a 10 inch zone then contains 2 inches of available water.

Available water capacity is often stated for a common depth of rooting (where 80 percent of the roots occur). This depth is at 60 inches or more in areas of the western United States that are irrigated and at 40 inches in the higher rainfall areas of the eastern United States. Some publications use classes of available water capacity. These classes are specific to the area in which they are used. Classes use such terms as very high, high, medium, and low.

Soil properties affect available water

Rock fragments reduce the available water capacity in direct proportion to their volume unless the rocks are porous.

Organic matter increases the available water capacity. Each 1 percent of organic matter adds about 1.5 percent to available water capacity.

Bulk density plays a role through its control of the pore space that retains available water. High bulk densities for for agiven soil tend to lower the available water capacity.

Osmotic pressure exerted by the soil solution is 0.3 - 0.4 times the electrical conductivity in mmhos/cm. A significant reduction in available water capacity requires an electrical conductivity of more than 8 mmhos/cm.

Texture has a significant effect. Some guidelines follow, assuming intermediate bulk density and no rock fragments.

Textures	Fraction Available Water
Sands, and loamy sands and sandy loams in which the sand is not dominated by very fine sand	Less than 0.10
Loamy sands and sandy loams in which very fine sand is the dominant sand fraction, and loams, clay loam, sandy clay loam, and sandy clay	0.10 - 0.15
Silty clay, and clay	0.10 - 0.20
Silt, silt loam, and silty clay loam	0.15 - 0.25

The **rooting depth** affects the total available water capacity in the soil. A soil that has a root barrier at 20 inches and an available water fraction of 0.20 has 4 inches of available water capacity. Another soil, that has a lower available water fraction of 0.10, would, if the roots

extended to a depth of 60 inches, have 6 inches of available water capacity. For shallow rooting crops, like onions, the available water below 1-2 feet has little significance. For deeper rooting crops, like corn, the available water at the greater depth is very important.

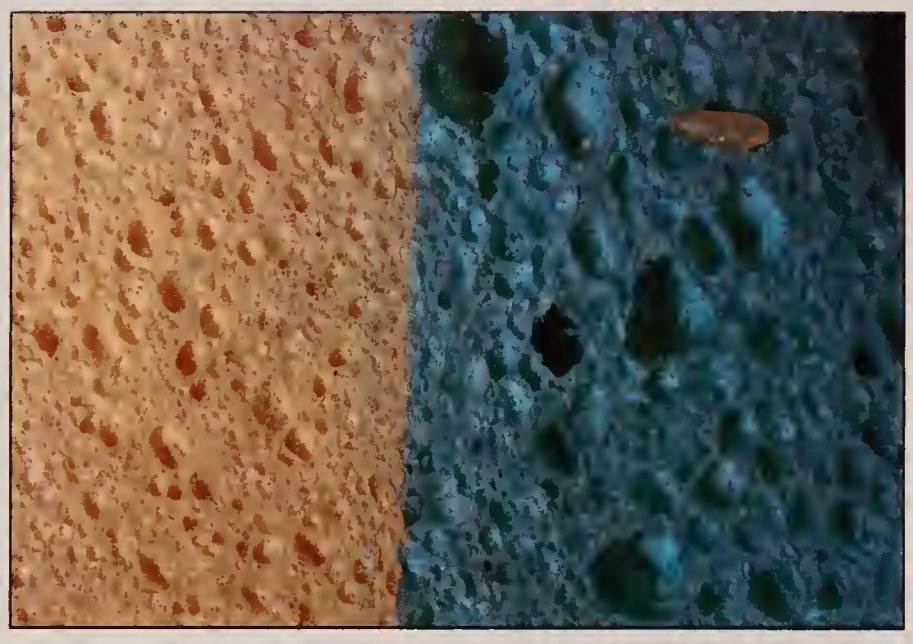


Figure 1: Pore size varies greatly between sponges.

Soil quality and available water

First, consider the difference between precipitation and evapotranspiration during the growing season. Second, decide what plants are involved. As indicated, some plants root less deeply than others.

Compare two soils that have different internal properties and climates selecting a crop that will extract water to a depth of 60 inches, unless there is a shallower root barrier.

Quantity		Soil Locations OK	ME
Rooting depth (in.)		30	60
Available water fraction	x	0.10	0.15
Available water amount (in.)	=	3.0	9.0
Evapotranspiration deficit (in./day)	÷	0.17	0.04
Time available water satisfies deficit (days)	=	18	222

* Evapotranspiration deficit is the monthly precipitation subtracted from monthly evapotranspiration. Calculate the average daily deficit for the month with the largest deficit.

Soil quality with respect to available water is better for the soil from Maine (ME), because of both the internal properties and the lower evapotranspiration deficit.

Figure 2: Available water capacity is greater with small pore size.

Improving the available water

Apply organic matter to the surface or mix into the upper few inches to increase the available water fraction near the surface. Available water near the surface is especially important at the seedling stage while roots are very shallow.

Maintain salts below the root zone. Keep infiltration high, reduce evaporation with a residue cover, minimize tillage, avoid mixing the lower soil layers with the surface, and plant seeds and seedlings on the furrow edges.

Minimize compaction by reducing the weight of vehicles and the amount of traffic, especially when the soil is moist or wet. Break up compacted layers when needed by ripping, and effectively expand the depth of the soil and increase the available water capacity.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Information Sheet

Soil Quality Resource Concerns: Salinization

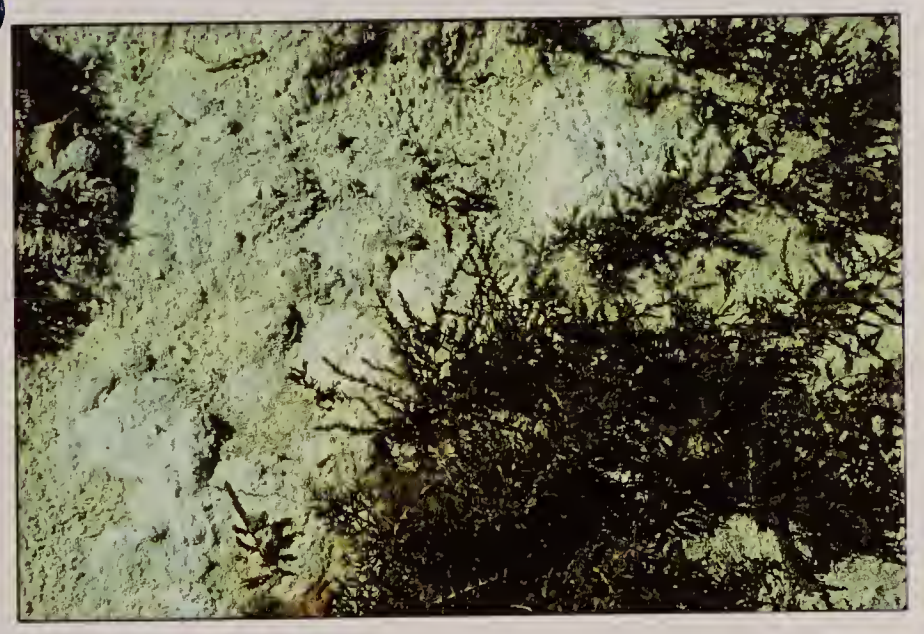
USDA Natural Resources Conservation Service January 1998

What is salinization?

Salinization is the process by which water-soluble salts accumulate in the soil. Salinization is a resource concern because excess salts hinder the growth of crops by limiting their ability to take up water. Salinization may occur naturally or because of conditions resulting from management practices.

Any process that affects the soil-water balance may affect the movement and accumulation of salts in the soil. These processes include:

- hydrology
- climate
- irrigation
- drainage
- plant cover and rooting characteristics
- farming practices



What causes salinization?

Salinization on the soil surface occurs where the following conditions occur together:

- the presence of soluble salts, such as sulfates of sodium, calcium, and magnesium in the soil
- a high water table
- a high rate of evaporation
- low annual rainfall

In semiarid areas, salinization often occurs on the rims of depressions and edges of drainageways, at the base of hillslopes, and in flat, low-lying areas surrounding sloughs and shallow bodies of water. These areas receive additional water from below the surface, which evaporates, and the salts are left behind on the soil surface.

Summer fallow management practices may cause increased salinization by increasing the soil moisture content to the point that water moves to seeps on hillslopes. Salts accumulate as the water evaporates from these seeps.

What are some indicators of soil salinity?

Early signs:

- increased soil wetness in semiarid and arid areas to the point that the soil does not support equipment
- the growth of salt-tolerant weeds
- irregular patterns of crop growth and lack of plant vigor

Advanced signs:

- white crusting on the surface
- a broken ring pattern of salts adjacent to a body of water
- white spots and streaks in the soil, even where no surface crusting is visible
- the presence of naturally growing, salt-tolerant vegetation

Soil salinity can be estimated by measuring the electrical conductivity of the soil solution. Electrical conductivity increases in a solution in direct proportion to the total concentration of dissolved salts.

What are some effects of salinization?

Salts in the soil increase the efforts by plant roots to take in water. High levels of salt in the soil have a similar effect as droughtiness by making water less available for uptake by plant roots.

Few plants grow well on saline soils; therefore, salinization often restricts options for cropping in a given land area.

Salinization degrades the quality of shallow ground water and surface water resources, such as ponds, sloughs, and dugouts.

How can salinity problems be managed?

Reducing the severity and extent of soil salinity is primarily a problem of water management. Water management can be addressed in two ways: (1) by managing the area contributing excess water to the soil (recharge area) or (2) by managing the area where the excess water comes to the surface (discharge area).

Recharge management:

- Decrease excess water from infiltrating into the soil in recharge areas of seeps by diverting surface water to downslope ponds.
- Maintain the water table at a low, safe level. Do not over irrigate. In some areas, over irrigation and the lack of natural drainage has raised the water tables, which may require the use of an artificial drainage system. Discharge of salty waters from these drains may contribute to other offsite problems.
- Irrigate to maintain salts at a level below the root zone in the soil.
- Use cropping and tillage systems that promote adequate infiltration and permeability. This includes building organic matter for soil aggregation and avoiding compaction.
- Plant crops that use the available soil moisture. Shallow-rooted crops may not extract excess subsoil moisture that can lead to salinity.
- Remove excess water from recharge areas of seeps by using actively growing, deep-rooted plants. Perennial plants and forages, especially alfalfa, are useful for this purpose because they have a longer growing season and take up more water from a greater depth in the soil than annual plants. Forages may also increase organic matter in the soil and improve soil structure.
- Return manure and crop residue to the soil to increase soil-water retention.
- Reduce summer fallow by continuous cropping.
- Manage snow so that it is evenly distributed and does not pond on thawing.

Discharge management:

- Grow salt-tolerant crops.
- Convert to permanent soil cover with salt-tolerant crops in high risk areas.
- Reduce deep tillage, which may bring up salts from deeper soil horizons.
- Plant forage crops or trees next to bodies of water to increase water use.
- Install artificial drainage systems in severely affected areas only.
- Eliminate seepage from irrigation canals, dugouts, and ponds.

Generally, control measures should take an integrated approach involving cropping, structural methods, and tillage systems.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Information Sheet

Soil Quality Concerns: Pesticides

USDA Natural Resouces Conservation Service January 1998

What are pesticides?

Pesticides are synthetic organic chemicals used to control weeds in fields and lawns, and unwanted or harmful pests, such as insects and mites that feed on crops. Pesticides are divided into categories according to the target organisms they are designed to control (e.g., insecticides control insects).

Herbicides are by far the most commonly used pesticides in the United States. They range from non selective to highly selective for control of specific weeds in specific crops, with different products having postemergence, preplant, and preemergence uses. Insecticides are second in usage, and fungicides are third.

Effects of Pesticides on Soil Quality

The capacity of the soil to filter, buffer, degrade, immobilize, and detoxify pesticides is a function or quality of the soil. Soil quality also encompasses the impacts that soil use and management can have on water and air quality, and on human and animal health. The presence and bio-availability of pesticides in soil can adversely impact human and animal health, and beneficial plants and soil organisms. Pesticides can move off-site contaminating surface and groundwater and possibly causing adverse impacts on aquatic ecosystems.

What are pesticide formulations?

The formulation is the chemical and physical form in which the pesticide is sold for use. The active ingredient (a.i.) is the chemical in the formulation that has the specific effect on the target organism. The formulation improves the properties of the pesticides for storage, handling, application, effectiveness, or safety. Examples of formulated products are wettable powders and water-dispersible granules. A single pesticide is often sold in several different formulations, depending on use requirements and application needs.

Pesticide mode of action

Mode of action refers to the mechanism by which the pesticide kills or interacts with the target organism.

- Contact pesticides kill the target organism by weakening or disrupting the cellular membranes; death can be very rapid.
- Systemic pesticides must be absorbed or ingested by the target organism to disrupt its physiological or metabolic processes; generally they are slow acting.

How effective the pesticides are at killing the target organisms (efficacy) depends on the properties of the pesticide and the soil, formulation, application technique, agricultural management, characteristics of the crop, environmental or weather conditions, and the nature and behavior of the target organism.

Fate of pesticides in the environment

Ideally, a pesticide stays in the treated area long enough to produce the desired effect and then degrades into harmless materials. Three primary modes of degradation occur in soils:

- biological - breakdown by micro-organisms
- chemical - breakdown by chemical reactions, such as hydrolysis and redox reactions
- photochemical - breakdown by ultraviolet or visible light

The rate at which a chemical degrades is expressed as the half-life. The half-life is the amount of time it takes for half of the pesticide to be converted into something else, or its concentration is half of its initial level. The half-life of a pesticide depends on soil type, its formulation, and environmental conditions (e.g., temperature, moisture). Other processes that influence the fate of the chemical include plant uptake, soil sorption, leaching, and volatilization. If pesticides move off-site (e.g., wind drift, runoff, leaching), they are considered to be pollutants. The potential for pesticides to move off-site depends on the chemical properties and formulation of the pesticide, soil properties, rate and method of application, pesticide persistence, frequency and timing of rainfall or irrigation, and depth to ground water.

Retention of pesticides in the soil

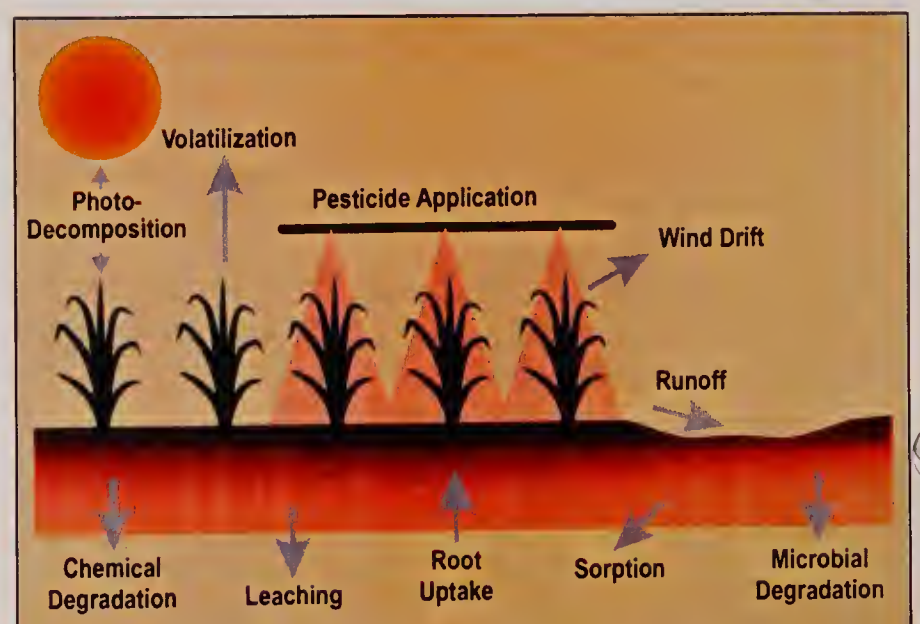
Retention refers to the ability of the soil to hold a pesticide in place and not allow it to be transported. Adsorption is the primary process of how the soil retains a pesticide and is defined as the accumulation of a pesticide on the soil particle surfaces. Pesticide adsorption to soil depends on both the chemical properties of the pesticide (i.e., water solubility, polarity) and properties of the soil (i.e., organic matter and clay contents, pH, surface charge characteristics, permeability). For most pesticides, organic matter is the most important soil property controlling the degree of adsorption.

For most pesticides, the degree of adsorption is described by an adsorption distribution coefficient (K_d), which is mathematically defined as the amount of pesticide in soil solution divided by the amount adsorbed to the soil.

Pesticide toxicity

The toxicity level of a pesticide depends on the deadliness of the chemical, the dose, the length of exposure, and the route of entry or absorption by the body. Pesticide degradation in soil generally results in a reduction in toxicity; however, some pesticides have breakdown products (metabolites) that are more toxic than the parent compound.

Pesticides are classified according to their potential toxicity to humans and other animals and organisms, as restricted-use (can only be purchased and applied by certified persons who have had training in pesticide application), and general use (may be purchased and applied by any person).



Fate of pesticides in the environment (after Aislabie and Lloyd-Jones).

Use and application considerations

- Apply pesticides at the lowest effective level.
- Avoid unnecessary pesticide treatments.
- Use Integrated Pest Management.
- Follow all label instructions.
- Apply proper rates and times as label indicates.
- Calibrate application equipment.
- Apply formulations that minimize drift.
- Use safety equipment when handling.
- Store and dispose of pesticide containers properly.
- Use biological controls when appropriate.
- Alter farming or cropping systems to control pests.
- Use disease and insect resistant crop varieties.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Indicators: pH

USDA Natural Resources Conservation Service January 1998

What is pH?

Soil pH is a measure of the acidity or alkalinity in the soil. It is also called soil reaction.

The most common classes of soil pH are:

Extremely acid	3.5 – 4.4
Very strongly acid	4.5 – 5.0
Strongly acid	5.1 – 5.5
Moderately acid	5.6 – 6.0
Slightly acid	6.1 – 6.5
Neutral	6.6 – 7.3
Slightly alkaline	7.4 – 7.8
Moderately alkaline	7.9 – 8.4
Strongly alkaline	8.5 – 9.0

What is the significance of pH?

Availability of Nutrients
Soil pH influences the solubility of nutrients. It also affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil. Soil pH thus affects the availability of several plant nutrients.

A pH range of 6 to 7 is generally most favorable for plant growth because most plant nutrients are readily available in this range. However, some plants have soil pH requirements above or below this range.

Soils that have a pH below 5.5 generally have a low availability of calcium, magnesium, and phosphorus. At these low pH's, the solubility of aluminum, iron, and boron is high; and low for molybdenum.

At pH 7.8 or more, calcium and magnesium are abundant. Molybdenum is also available if it is present in the soil minerals. High pH soils may have an inadequate availability of iron, manganese, copper, zinc, and especially of phosphorus and boron.

Micro-organisms
Soil pH affects many micro-organisms. The type and population densities change with pH. A pH of 6.6 to 7.3 is favorable for microbial activities that contribute to the availability of nitrogen, sulfur, and phosphorus in soils.

Pesticide Interaction
Most pesticides are labeled for specific soil conditions. If soils have a pH outside the allowed range, the pesticides may become ineffective, changed to an undesirable form, or may not degrade as expected, which results in problems for the next crop period.

Mobility of heavy metals
Many heavy metals become more water soluble under acid conditions and can move downward with water through the soil, and in some cases move to aquifers, surface streams, or lakes.

Corrosivity
Soil pH is one of several properties used as a general indicator of soil corrosivity. Generally, soils that are either highly alkaline or highly acid are likely to be corrosive to steel. Soils that have pH of 5.5 or lower are likely to be highly corrosive to concrete.

What controls soil pH?

The acidity or alkalinity in soils have several different sources. In natural systems, the pH is affected by the mineralogy, climate, and weathering. Management of soils

often alters the natural pH because of acid-forming nitrogen fertilizers, or removal of bases (potassium, calcium, and magnesium). Soils that have sulfur-forming minerals can produce very acid soil conditions when they are exposed to air. These conditions often occur in tidal flats or near recent mining activity where the soil is drained.

The pH of a soil should always be tested before making management decisions that depend on the soil pH.

How is pH measured?

A variety of kits and devices are available to determine the pH in the field. The methods include:

- dyes
- paper strips
- glass electrodes.

Soil pH can change during the year. It depends on temperature and moisture conditions, and can vary to as much as a whole pH unit during the growing season. Since pH is a measure of the hydrogen ion activity [H^+], many different chemical reactions can affect it. Temperature changes the chemical activity, so most measurements of pH include a temperature correction to a standard temperature of 25 degrees C (77°F). The soil pH generally is recorded as a range in values for the soil depth selected.

How is soil pH modified?

A soil pH below about 5.6 is considered low for most crops. Generally, the ideal pH range is between 6.0 and 7.0. Liming is a common method to increase the pH. It involves adding finely ground limestone to the soil. The reaction rate for limestone increases when soil temperatures are warm and soil moisture is high. If the limestone is more finely ground, the reaction is faster.

The amount of limestone to apply depends on the amount of organic matter and clay as well as the pH. Fertility testing laboratories that have local experience make this determination.

A soil pH that is more than about 8.0 is considered high for most crops. Soils that have a pH in this range are often also calcareous.

Calcareous soils have a high content of calcium carbonate. The pH of these soils does not change until most of the calcium carbonate is removed. Acids that are added to the soil dissolve the carbonates and lower the soil pH. Treatments with acid generally are uneconomical for soils that have a content of calcium carbonate of more than about 5%. Because phosphorus, iron, copper, and zinc are less available to plants in calcareous soils, nutrient deficiencies are often apparent. Applications of these nutrients are commonly more efficient than trying to lower the pH.

When the soil pH is above 8.6, sodium often is present. These soils generally do not have gypsum or calcium carbonates, at least not in the affected soil horizons. Addition of gypsum followed by leaching using irrigation is a common reclamation practice. However, salts flushed into drainage water may contaminate downstream waters and soils.

The application of anhydrous ammonia as a nitrogen fertilizer contributes to lowering the soil pH. In some parts of the country, applications of ammonia lower the surface soil pH from ranges of 6.6 to 7.3 to below 5.6. This reduction can be easily overlooked in areas of no-till cropping unless the pH is measured in the upper 2 inches.

Chemical amendments that contain sulfur generally form an acid, which lowers the soil pH.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Soil Quality Information Sheet

Soil Quality Indicators: Infiltration

USDA Natural Resouces Conservation Service January 1998

What is Infiltration?

Infiltration is the process of water entering the soil. The rate of infiltration is the maximum velocity at which water enters the soil surface. When the soil is in good condition or has good soil health, it has stable structure and continuous pores to the surface. This allows water from rainfall to enter unimpeded throughout a rainfall event. A low rate of infiltration is often produced by surface seals resulting from weakened structure and clogged or discontinuous pores.

Why is infiltration a concern?

Soil can be a excellent temporary storage medium for water, depending on the type and condition of the soil. Proper management of the soil can help maximize infiltration and capture as much water as allowed by a specific soil type.

If water infiltration is restricted or blocked, water does not enter the soil, and it either ponds on the surface or runs off the land. Thus, less water is stored in the soil profile for use by plants. Runoff can carry soil particles and surface applied fertilizers and pesticides off the field. These materials can end up in streams and lakes or in other places where they are not wanted.

Soils that have reduced infiltration have an increase in the overall amount of runoff water. This excess water can contribute to local and regional flooding of streams and rivers or results in accelerated soil erosion of fields or streambanks.

In most cases, maintaining a high infiltration rate is desirable for a healthy environment. However, soils that transmit water freely throughout the entire profile or into tile lines need proper chemical management to ensure the protection of groundwater and surface water resources.

Soils that have reduced infiltration can become saturated at the surface during rainfall. Saturation decreases soil strength, increases detachment of particles, and enhances the erosion potential. In some areas that have a steep slope, surface material lying above a compacted layer may move in a mass, sliding down the slope because of saturated soil conditions.

Decreases in infiltration or increases in saturation above a compacted layer can also cause nutrient deficiencies in crops. Either condition can result in anaerobic conditions which reduce biological activity and fertilizer use efficiencies.

What factors influence infiltration?

A number of factors impact soil infiltration. Some of these are:

- **Texture:** The type of soil (sandy, silty, clayey) can control the rate of infiltration. For example, a sandy surface soil normally has a higher infiltration rate than a clayey surface soil. A soil survey is a recorded map of soil types on the landscape.

- **Crust:** Soils that have many large surface connected pores have higher intake rates than soils that have few such pores. A crust on the soil surface can seal the pores and restrict the entry of water into the soil.

- **Compaction:** A compacted zone (plowpan) or an impervious layer close to the surface restricts the entry of water into the soil and tends to result in ponding on the surface.

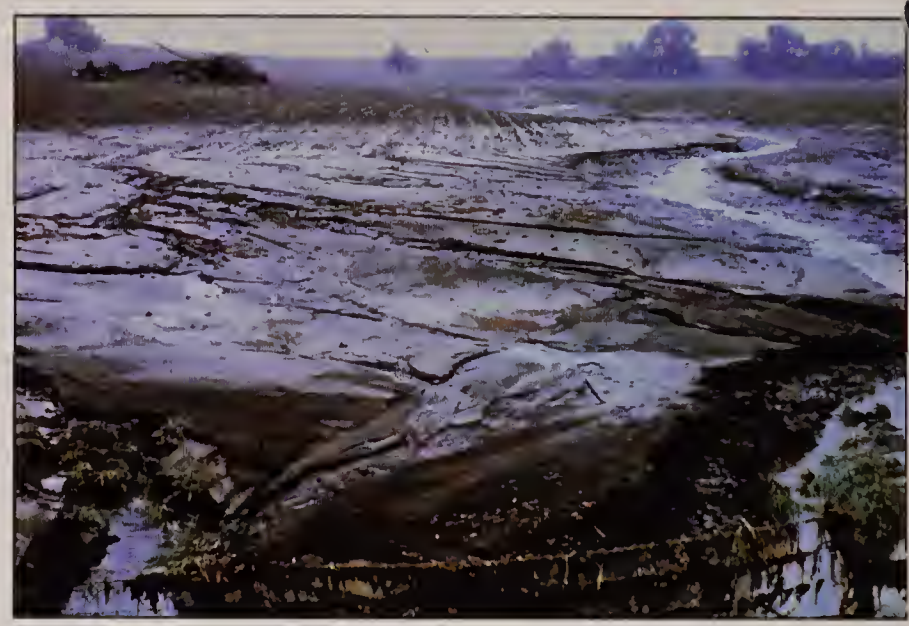
- **Aggregation and Structure:** Soils that have stable strong aggregates as granular or blocky soil structure have a higher infiltration rate than soils that have weak, massive, or platelike structure. Soils that have a smaller structural size have higher infiltration rates than soils that have a larger structural size.

- **Water Content:** The content or amount of water in the soil affects the infiltration rate of the soil. The infiltration rate is generally higher when the soil is initially dry and decreases as the soil becomes wet. Pores and cracks are open in a dry soil, and many of them are filled in by water or swelled shut when the soil becomes wet. As they become wet, the infiltration rate slows to the rate of permeability of the most restrictive layer.

- **Frozen Surface:** A frozen soil greatly slows or completely prevents water entry.

- **Organic Matter:** An increased amount of plant material, dead or alive, generally assists the process of infiltration. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event.

- **Pores:** Continuous pores that are connected to the surface are excellent conduits for the entry of water into the soil. Discontinuous pores may retard the flow of water because of the entrapment of air bubbles. Organisms such as earthworms increase the amount of pores and also assists the process of aggregation that enhances water infiltration.



How can infiltration be increased?

A number of management options can help increase soil infiltration:

- Decrease compaction by reducing tillage and by avoiding the use of machinery when the soils are wet. Keep the number of trips across a field to a minimum and follow the same wheel tracks for all operations, if posssible.
- Decrease the formation of crusts by maintaining plant cover or by practicing residue management to reduce the impact of raindrops. Use a rotary hoe or row cultivator to shatter crust.
- Increase the amount of organic materials added to the soil to increase the stability of soil aggregates.
- Decrease or eliminate tillage operations to help maintain surface connected pores and encourage biological activity.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

SOIL RESILIENCE

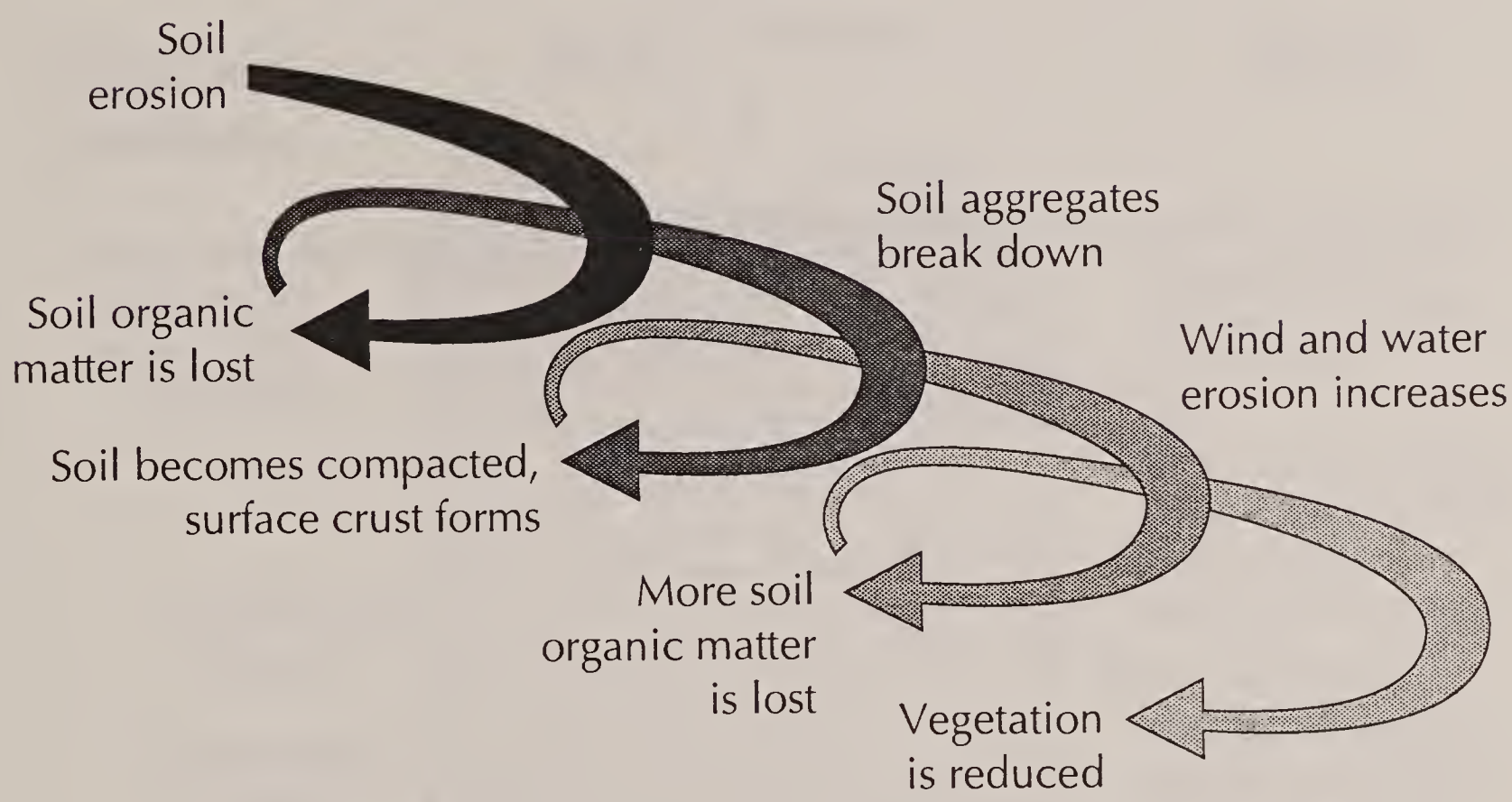
Soil systems like most natural systems, are in dynamic equilibrium. Most changes are slow and imperceptible particularly when viewed in the time frame of human lifespan. However, catastrophic events such as high intensity storms can accelerate erosion processes resulting in measurable changes. The changes are mainly in the structure and composition of the material and such changes are referred to as "structural changes". Changes are measurable directly or indirectly or may be inferred from behavior of the system. Many of the changes are related to uses of the soil. These performance-related changes are more important as they can be quantified, particularly in economic value terms.

Many soil systems have been subject to degradation either naturally or induced by man. Sustainable systems may be established on these soils. However an unanswered question is the ability of the soil to be restored to it's previous performance level. Basically this is the concept of "resilience" which is defined as: the ability of the system to revert to it's original or near original performance or state that existed before the impressed forces altered. it.

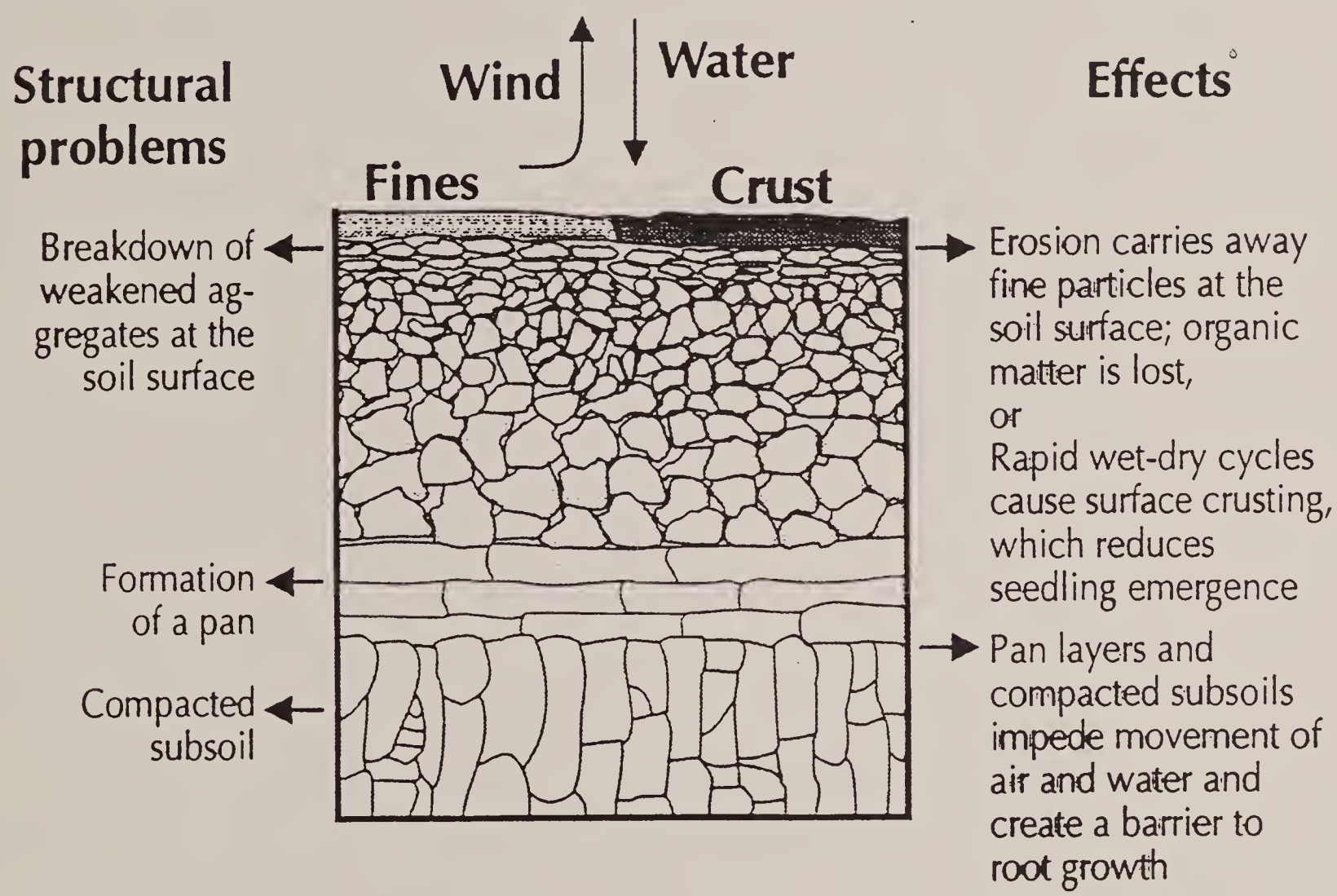
Principal Physical and Chemical Properties Adversely Affected by Soil Degradation Process Causing Decline in Soil Quality/Health

Soil Degradation Process	Soil Properties Adversely Affected
Erosion	Depth-decrease in rooting volume, topsoil loss
	Water-holding capacity-decrease due to decline in organic matter, fine mineral colloids, aggregation and depth
	Cation exchange capacity-the most reactive colloids lost, leaving sand and gravel with little nutrient retention capacity.
	Bulk density-more compact and dense horizons exposed.
	PH-increase or decrease, depending on underlying materials.
	Combination of above-structural collapse and poor tilth.
Compaction	Bulk density and penetration resistance-increase results in low oxygen diffusion and restricted root development.
	Infiltration rate-decline in water entry into the soil decreases water storage and increases runoff and soil loss.
	Hydraulic conductivity-poor drainage, low oxygen diffusion rate, cod soils.
Acidification	pH decrease
	Nutrient availability.
Salinization	Electrical conductivity-increase
Sodification	pH-increase
	Hydraulic conductivity-decrease due to dispersion of soil colloids resulting from increase in ESP.
	Bulk density-increase due to compact surface/subsurface horizons.
Water-logging	Aeration, nutrient availability
Chemical degradation	Nutrient depletion, nutrient imbalance toxic chemicals affecting quantity and quality of crops/forage.
Biological degradation	Organic matter, microbial biomass and diversity of soil fauna affect soil structure, nutrient release, nutrient retention and other properties.

The downward-spiralling effect of soil structural degradation



Structural problems throughout the soil profile and effects of degradation



(after Anon. 1994)

Data Collection
and Evaluation

SOIL QUALITY/HEALTH DATA COLLECTION AND EVALUATION

The NRI soil sampling protocol for the Colorado NRI Pilot Test is included for your review and information. We are currently reviewing and evaluating the soil data collected for the NRI pilot to determine which data is most valuable for soil quality/health assessment. Results of the evaluations and recommendations will be distributed.

Cooperators in the Colorado NRI pilot included the BLM, National Soil Survey Center (NRCS), National Soil Tilth Laboratory, Soil/Quality Institute, NRI Division of NRCS and Agriculture Research Service.

NRI PLOT

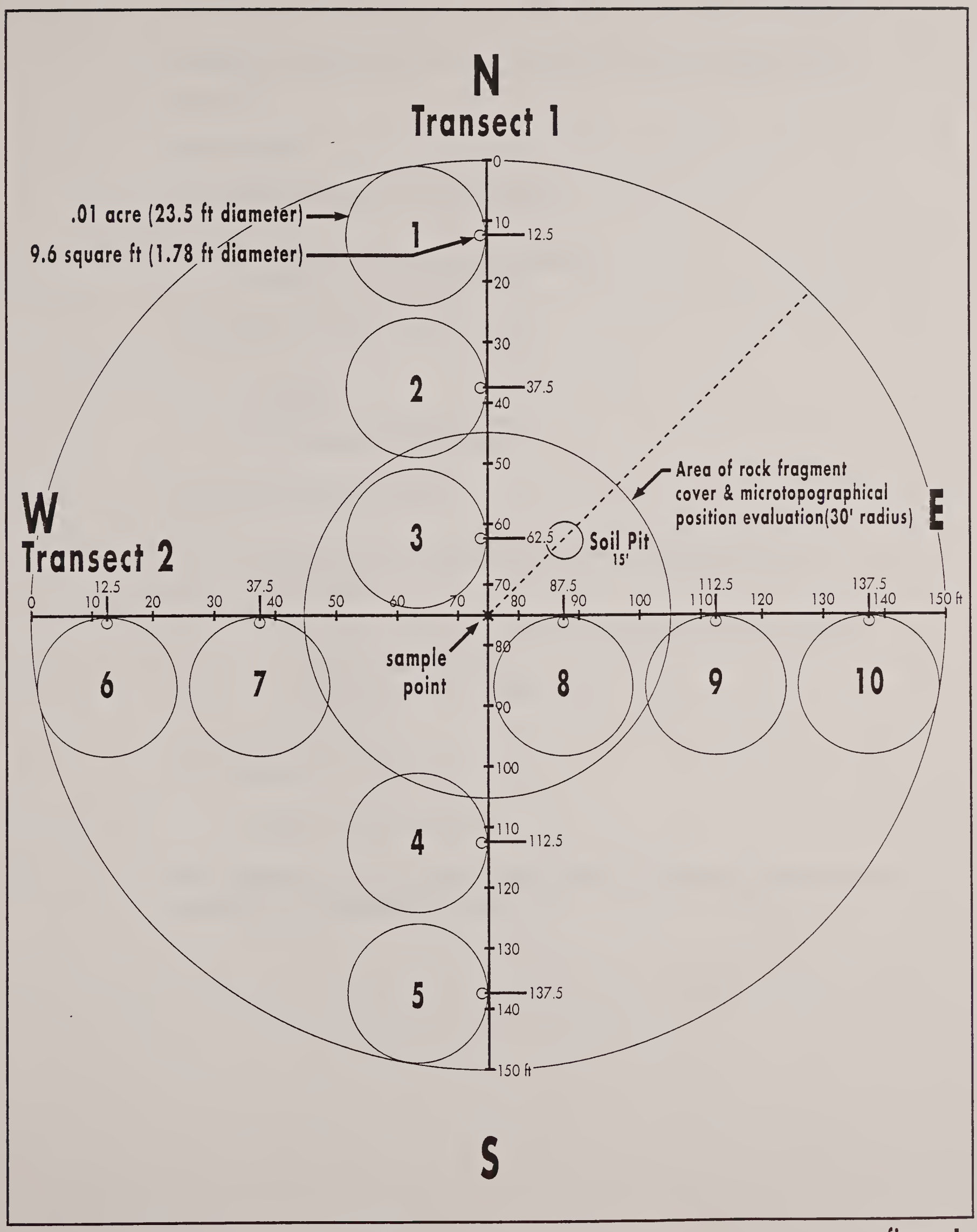


figure 1a

FIELD METHODOLOGY -- SOIL QUALITY SUB-SAMPLE

"FROM THE GROUND UP -- A PERSPECTIVE OF RANGELAND HEALTH"

APPROACH:

1) Soil Identification and Verification

   - Identify the plant growth material
   - Correlate to ecological site

2) Setting and Site Characteristics

   - Climate
   - Landform and micro-relief
   - Associated land features

3) Soil Quality Evaluation

   - Sample basic soil attributes and near-surface (30 cm) morphology

     - Physical - Texture, structure, aggregate stability, crusts zones of bulk density
     - Chemical - pH, EC (salt), OM
     - Biological

4) Soil Sample Collection

   - Primary surface sample

Provides plant growth medium information in a sequence for rangeland vegetation and health evaluations.

NRI 1997 COLORADO PILOT
SOIL INFORMATION

All Sites

Two types of soil information will be collected at all sites:

- Profile description (from pit)
  Objective: verify soil series and provide general information on soil profile.
  Justification: soil series identification required for NRI.
  soil profile information used in identification of range sites.

- Near-surface morphology to 20 cm (from pit)
  Objective: describe soil physical quality related to water infiltration and root penetration at pit
  Justification: enhances soil profile description by providing information which is more closely related to rangeland health

  A sample will be removed from the top 5 cm of the pit for future analysis.

Selected Sites

Additional information will be collected at 16 points within the 150 m plot . While the profile information applies only to a single point within the plot, the information collected below can be used to make statements about the entire site. This information can be related directly to the vegetation data, which are collected at the same scale. Stratifying data collection by vegetative cover strata will also assist interpretation pit-scale information in context of site-scale variability.

- Soil surface stability
  Objective: characterize resistance of soil to detachment (erodibility) and physical crusting
  Justification: provides data reflecting soil quality at scale at which vegetation data are collected
  also related to soil organic matter content, soil biological activity which are associated with nutrient cycling, resistance and resilience has been identified as a potential early-warning indicator of rangeland degradation

- Soil samples for laboratory analysis
  Objective: assess soil quality using standard laboratory methods
  Justification: provides additional information on soil properties and processes related to critical soil functions

  Lab samples collected at the 16 points will be combined in the field into 1 to 4 composite samples based on cover type (bare, grass, shrub, tree). The samples will be collected from two depths, yielding up to 8 samples/point (4 - 6 for most sites, depending on number of cover types).

Table 2. Site characteristics recorded for the 1996 NRI pilot project.

Identify soil type - auger hole
Landscape position - surface config.
Surface relief - tillage
Visual erosion features
Rock fragments - surface cover %
Land use/crop history
Soil rooting barriers
Irrigation

Table 3. Near surface point soil quality evaluation (Bob Grossman, NCSS).

Pedon description to 30 cm depth
horizon, depth, % clay & sand,
water state, most consistence,
structure (shape, grade, size),
and macropores
Measure crust expression
Measure bulk density
zone of maximum density

Table 4. Soil quality indicators measured in NRI 1996 pilot project.

Organic C	Aggregate stability
Organic C & N	Potentially mineralizable N
CEC	Particulate organic matter
Ext. Al & bases	Microbial biomass
pH	Basal respiration
EC & SAR	Herbicide residue
Texture	PAH

Illustration 7
Colorado BLM 1997
Test Pilot Worksheet

Page 6

PSU NUMBER_ _ _ _ _ _ _ _ _ _ _ _ _

POINT NUMBER☐ SITE 1 or 2 (CIRCLE)

SOILS DATA
BACKGROUND INFORMATION

Soil Survey Area Symbol _ _ _ _ _

Soil Map Unit Symbol _ _ _ _ _ _

S5ID _ _ _ _ _ _ _ _

Soil Taxonomic Classification____________________

Enter soil taxonomic classification if soil series S5ID is not entered.

Soil Component Name (60Characters)_ _

☐ 01Named Map Unit Component, ☐ 02 Named Inclusion, ☐ 03 Unnamed Inclusion

Ecological Site Number____________________ Ecological Site Name____________________

☐ 01 Fits the Ecological Site Description, ☐ 02 Marginally Fits the Site Description, ☐ 03 Does Not Fit the Site Description

SETTING

1. Elevation (feet): ______________
2. Mean Annual Precipitation (Range in inches)________to__________
3. Frost Free Period (Range in days)________to__________
4. Landform (Check one)

☐ 01 Badland, ☐ 02 Basin, ☐ 03 Bench (structural), ☐ 04 Breaks, ☐ 05 Bluffs, ☐ 06 Butte, ☐ 07 Cliff, ☐ 08 Cove, ☐ 09 Cuesta , ☐ 10 Dune, ☐ 11 Escarpment, ☐ 12 Fan, ☐ 13 Floodplain, ☐ 14 Hill-hillslope, ☐ 15 Hogback, ☐ 16 Knoll, ☐ 17 Marsh/Bog, ☐ 18 Mesa, ☐ 19 Mountain Slope, ☐ 20 Outcrop, ☐ 21 Piedimont, ☐ 22 Plain, ☐ 23 Plateau, ☐ 24 Playa, ☐ 25 Ridge, ☐ 26 Side Slope, ☐ 27 Swale, ☐ 28 Tableland, ☐ 29 Terrace, ☐ 30 Wash, ☐ 31 Other________

5. Landscape Position (Check one)(if other than summit or flat must complete section 9 below)

Hillslope and Sideslope: ☐ 01 Summit, ☐ 02 Shoulder, ☐ 03 Backslope, ☐ 04 Footslope, ☐ 05 Toeslope

Terrace: ☐ 06 Riser, ☐ 07 Tread

Flat: ☐ 08 Flat

6. Vertical Slope Shape (Check one): ☐ 01 Concave ☐ 02 Convex ☐ 03 Linear

7. Horizontal Slope Shape (Check one): ☐ 01 Concave ☐ 02 Convex ☐ 03 Linear

8. Slope gradient (%)________

9. Slope Aspect (Check one): ☐ 01 North, ☐ 02 North East, ☐ 03 East, ☐ 04 South East, ☐ 05 South, ☐ 06 South West, ☐ 07 West, ☐ 08 North West

10. Plot microtopographic description (Check all applicable):
☐ 01 Shrub-Coppice Dune/Intercoppice, ☐ 02 Terracette, ☐ 03 Playette, ☐ 05 Other____________________

11. Soil pit microtopographic position (Check one):
☐ 01 Shrub-Coppice Dune, ☐ 02 Coppice bench, ☐ 03 Intercoppice, ☐ 04 Terracette, ☐ 05 Playette, ☐ 07 Other__________

12. Soil pit surface cover (Check one): ☐ 01 Bare, ☐ 02 Litter, ☐ 03 Cryptogam (moss/lichen), ☐ 04 Grass, ☐ 05 Shrub

PSU NUMBER_ _ _ _ _ _ _ _ _ _ _ _ _ _

POINT NUMBER ☐ SITE 1 or 2 (CIRCLE)

PARENT MATERIAL AND GEOLOGY

Parent Material (Check one for each line)

1. Kind: ☐ 01 Alluvium, ☐ 02 Colluvium, ☐ 03 Eolian, ☐ 04 Mixed, ☐ 05 Residuum, ☐ 06 Glacial, ☐ 07 Organic
2. Texture: ☐ 01 Sandy, ☐ 02 Loamy, ☐ 03 Clayey
3. Reaction: ☐ 01 Acidic, ☐ 02 Alkaline, ☐ 03 Calcareous, ☐ 04 Noncalcareous, ☐ 05 Saline

Bedrock:

1. Type (Select one):

   Sedimentary: ☐ 01 Sandstone, ☐ 02 Shale, ☐ 03 Limestone, ☐ 04 Conglomerate, ☐ 05 Other _____

   Igneous: ☐ 06 Granite, ☐ 07 Basalt, ☐ 08 Rhyolite, ☐ 09 Other _____

   Metamorphic: ☐ 10
2. Reaction (Select one): ☐ 01 Acidic, ☐ 02 Alkaline, ☐ 03 Calcareous, ☐ 04 Noncalcareous, ☐ 05 Saline

SOIL IDENTIFICATION AND VERIFICATION

Brief Profile Description to 60 inches (40 inches is sufficient)

Depth	Horizon	Modifier Texture	Color			Effervesc	*EC	*pH
			Hue	Value	Chroma			
0 to								
to								
to								
to								
to								
to								

* Populate with data only if significant

Root Barrier depth: _____in.

Type (Select one): ☐ 01 None, ☐ 02 Paralithic Contact, ☐ 03 Lithic Contact,
☐ 04 Petrocalcic, ☐ 05 Duripan, ☐ 06 Compacted

Rock Fragments (Surface) Percent_____ Class_____

Rock Fragments (Control Section) Percent_____ Class_____

Shape-Round Classes

GRF - Fine Gravel	0.2 - 0.5 cm diameter
GRM - Medium Gravel	0.5 - 2.0 cm diameter
GRC - Coarse Gravel	2.0 - 7.6 cm diameter
CB - Cobble	7.6 - 25.0 cm diameter
ST - Stone	25 - 60.0 cm diameter
BY - Boulder	> 60 cm diameter

Shape-Flat Classes

CN - Channer	0.2 - 15 cm long
FL - Flagstone	15.0 - 38 cm long
STF - Stone	38.0 - 60 cm long
BYF - Boulder	> 60 cm long

Notes: _____

PSU NUMBER_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Page 8

POINT NUMBER ☐ SITE 1 or 2 (CIRCLE)

SOILS INFORMATION

NEAR SURFACE MORPHOLOGY to 30 cm (For Soil Quality)

Depth	Horizon	%Clay	Water State	Structure			Moisture Rupture Resistance	*EC	*pH
				Grade	Size	Shape			
0 to									
to									
to									
to									
to									
to									

*Optional Data

Structure

Water State
D Dry
SM Slightly Moist
MM Mod. Moist
VM Very Moist
W Wet

Grade
1 Weak
2 Moderate
3 Strong

Size (if platty)
vf - very fine (very thin)
f - fine (thin)
m - medium (medium)
c - coarse (thick)
vc - very coarse (very thick)

Shape
gr - granular
sbk - sub-angular blocky
abk - angular blocky
pl - platy
pr - prismatic
cpr - columnar
m - massive
sg - single grained

Moist Rupture Resistance
L - Loose
VFr - Very Friable
Fr - Friable
Fi - Firm
Vfi - Very Firm
EFi - Extremely Firm

Zone of Maximum Bulk Density in top 30 cm:_____to_____cm

CRUST DESCRIPTION

Type (check all that apply): ☐ 01 Lichen, ☐ 02 Moss, ☐ 03 Mineral/other, ☐ 04 None

Complete the following section for mineral crust only...
Dry color:_____ Thickness (mm):_____
Dry Rupture Resistance (Select one): ☐ 01 Weak, ☐ 02 Moderate, ☐ 03 Strong, ☐ 04 Extremely Strong, ☐ 05 Too Wet,
Crust particle size class (check one): ☐ 01 Sandy, ☐ 02 Loamy, ☐ 03 Clayey

SOIL SAMPLES COLLECTED

Identify which soil samples were collected at the PSU-sample point

☐ 01 Primary Soil Sample - Soil Pit (0-5cm),

☐ 02 Soil quality transect samples (0-2.5 and 2.5-10 cm)
Composite by Cover Strata (Grass/Shrub/Tree/Bare)

NOTES: _____

SOILS DATA (Illustration 7)

NOTE: Portions of the following were taken from the NRLS "NRI Soil Quality Pilot Study Data Collection Instructions Draft 4/30/96," with additions and modifications to accommodate the Colorado Pilot NRI Rangeland Health Test. All Soil Quality information will be collected and entered into the Apple MessagePad 120 (Newton).

SPECIFIC POINT AND PROXIMITY AREA DEFINITION AND REPRESENTATION - Soil identification and verification for the specific point and proximity will be done 4 meters from the GPS point and in the northeast quadrant of the Rangeland transect, 45 degrees east of the north transect line and is known as site 1 (see figure 1). When the range sampling protocol crosses into a contrasting soil that produces a different range site (ecological site), the contrasting soil identification and verification will be done at the extreme end of the range transect that extends into the contrasting unit and will be identified as site 2 (see figure 2). The complete documentation process and primary soil sampling will be conducted on the additional soil component.

SOIL IDENTIFICATION AND VERIFICATION - Identify and verify the soil at the point with a brief profile description from a mini-soil pit and auger hole.

Soil survey area symbol is a unique five-character alpha numeric symbol that identifies all soil survey areas. The number is available in the National Soil Information System (NASIS). The symbol uses a state identifier, such as Colorado and three numbers for each survey area, for example, CO-115. Do not use the more broadly defined MLRA soil survey number. The soil survey area symbol is available from the state soil scientist. See supplement for a list of soil survey area symbols for each MLRA in the NRI pilot.

Soil map unit symbol is the map unit symbol used within the soil survey area to identify the soil delineation on the map and map legend. The soil map unit symbol is taken from the most recent published soil survey. If a published soil survey is not available, use the soil mapping symbol from the field sheets. If the area is not mapped, use the legend applicable to that county. Up to six characters can be used for this symbol. Capitalization of the symbol is important. If the symbol uses upper case or lower case letters, be sure to use them.

S51D is the SCS-SOI-5 Soil Interpretations Record number. Up to six characters are used for the entry. The S51D number represents the soil series and accompanying specific phase or other unit modifier for the soil series identified. It provides the final linkage of the soil identified at the NRI PSU point to the soil information data base.

The component name is the soil reference name (inclusions are identified as a component). The soil series name is usually used, but the component is sometimes a miscellaneous land type or soil family. Up to 60 characters are available for this entry. The entry provides the final linkage of the NRI point to soils information data base. Be sure to indicate whether the soil is a named component of the soil mapping unit, and named inclusion or and unnamed inclusion.

Ecological Site Number and Name. Identify the Ecological Site Number and Name based on the soil and setting of the sample point. The Ecological Site Number should include the Major Land Resource Area Number, Region number, site number, state and the precipitation zone an example is 49BY228CO for Mountain loam 15 to 20. Be sure to indicate whether the existing site matches the ecological site description, marginally matches, or doesn't match it at all. Be sure to indicate whether the ecological site description clearly depicts what is currently on the site (fits the site description), marginally fits the description, or doesn't fit it at all.

NOTE: Most BLM lands have highly variable landscapes with order 3 soil surveys with map units that are predominantly complexes, associations of 2 to 3 soil series, and undifferentiated units (See illustration 8 for kinds of soil mapping units.) There will be instances where the PSU sample points may not be on soil components named in the soil map unit name, but occurs on inclusions named in the map unit description or on named similar soil (soils with similar plant growth properties). In these instances, inclusions and named similar soils will be identified as the soil component.

During the soil identification and verification process, be sure to review and evaluate the range of characteristics allowed for the soil map unit component soils. Where PSU points occur on unmapped areas, it is the intent to map the PSU or identify the soils at the point with the map unit used in the soil survey area with accompaniment of assistance from the local soil survey staff within the soil survey area.

SETTING AND SITE CHARACTERISTICS

Elevation is the vertical distance from mean sea level to a point on the earth's surface. Enter the elevation in feet from the GPS instrument. Another option is to enter the range of elevation in feet obtained from a USGS quadrangle sheet (e.g. 5280 or 5280-5300).

Precipitation, Mean Annual. Precipitation refers to all forms of water that fall from the atmosphere and reach the ground is expressed as a range in total annual precipitation in inches (e.g. 10-13). This is the precipitation zone associated with the ecological site description.

Frost-free Period is the expected number of days between the last freezing temperature in spring and the first freezing temperature in the fall. It is expressed as a range of number of days (e.g. 125-140 days).

Landform is any physical, recognizable form or feature on the earth's surface, having a characteristic shape, and produced by natural causes (reference is made to PART 629 - Glossary of Landform and Geologic Terms NSH). Most common landform terms are shown below.

(1) Badland
(2) Basin
(3) Bench (structural)
(4) Breaks
(5) Bluffs
(6) Butte
(7) Cliff,
(8) Cove
(9) Cuesta
(10) Dune
(11) Escarpment
(12) Fan
(13) Floodplain
(14) Hill-hillslope
(15) Hogback
(16) Knoll
(17) Marsh/Bog
(18) Mesa
(19) Mountain Slope
(20) Outcrop,
(21) Piedimont
(22) Plain
(23) Plateau
(24) Playa
(25) Ridge
(26) Side Slope
(27) Swale,
(28) Tableland
(29) Terrace
(30) Wash
(31) Other_____

Position on the landform is described with the following:

(1) Hillslopes:
(1) summit
(2) shoulder
(3) backslope
(4) footslope
(5) toeslope

(2) Terraces:
(1) riser
(2) tread

(3) Flat:

Slope Shape is described both vertically down the slope and horizontally across the slope. **Vertical slope shape** terms are: concave, convex, and linear. **Horizontal slope shape** terms are: concave, convex, and linear.

Slope Gradient is the inclination of the surface of the soil from the horizontal expressed as a percentage (e.g. 10-25).

Slope Aspect is the direction toward which the surface of the soil faces. The direction is expressed as a compass point. Entries are north, northeast, east, southeast, south, southwest, west, northwest.

Microtopographical Position (Microrelief) Descriptions refer to local slight irregularities in form and height of land surface that are superimposed upon a larger landform, including such natural features as:

(1) shrub-coppice dune/intercoppice
(2) terracette (catsteps)
(3) playette
(4) none
(5) Other _____

Identify the microtopographical positions occurring within a 10-meter radius of the PSU sample point. See Illustration 9.

Soil Pit Micotopographic Position. Sample position is the microtopographical position that represents the physical area where the specific soil is identified and primary near-surface properties are evaluated. (See microtopographical description for list of features.

Parent Material. Identify type, kind, texture and reaction of parent material. (Unconsolidated)

	Kind		Texture		Reaction
1	alluvium	1	sandy	1	acidic
2	coluvium	2	loamy	2	alkaline
3	eolian	3	clayey	3	calcareous
4	mixed			4	noncalcareous
5	residuum			5	saline
6	glacial				
7	organic				

Geology - Bedrock Type. A general term for the solid rock (lithic and paralithic) that underlies the soil and other unconsolidated material that is exposed at the surface. Identify general type and chemical reaction. Note geologic formation name.

Type	Reaction
Sedimentary	1 acidic
sandstone	2 alkaline
shale	3 calcareous
limestone	4 noncalcareous
conglomerate	5 saline
Igneous	
granite	
basalt	
rhyolite	
Metamorphic	

BRIEF PROFILE DESCRIPTION TO 150 CM.

To identify and confirm the soil component at the point, dig a mini-soil pit and use a soil auger to briefly describe the main diagnostic soil features (use care not to disturb the sampling point).

The mini-soil pit should have approximately a 20-inch sampling face, 12 to 18 inches wide and 16-20 inches deep.

The sampling face is best facing the sun with the area behind it protected from any disturbance as it will be used for the soil identification process, the near surface soil properties and collection of the primary soil samples. Fill from the pit will be placed on a small tarp on one side of the pit to facilitate closing and minimize disturbance.

Depth begins with 0 and is entered in inches. Subdivide only those horizons necessary for confirmation of the soil series.

Horizon should correspond with normal horizon nomenclature.

Texture is the USDA texture with modifier. The entry should include the codes for texture modifier followed by the texture class. Terms used in lieu of texture are potential entries. Refer to Appendix B from Exhibit 618-75 of the 1993 version of the National Soil Survey Handbook.

Color is the Munsell notation for **hue, value,** and **chroma**. Use Munsell color charts. Use moist colors only.

Effervescence is the reaction of the soil with treatment to cold dilute (1N) hydrochloric acid. This data field only needs to be populated if it is significant in determining the soil series. Effervescence entries and their descriptions are:

(0)	None	
(1)	Very slightly effervescent	few bubbles seen
(2)	Slightly effervescent	bubbles readily seen
(3)	Strongly effervescent	bubbles form low foam
(4)	Violently effervescent	thick foam forms quickly

EC - Electrical Conductivity is the conductivity of an extract from a saturated soil paste. EC is a measure of the concentration of water-soluble salts in soil. Field measurements will be made with a field conductivity meter and recorded to the nearest mmhos/cm (e.g. 1-2).

pH (Reaction) - Soil reaction is a numerical expression of acidity or alkalinity of a soil. Field measurements will be made with a field pH meter or pH indicators and will be recorded to the nearest one-tenth pH (e.g. 7.4).

Root Barrier - Kind and Depth to Top. A root barrier is a physical restriction to rooting. The depth provides the physical limit for roots

within the upper 150 cm of soil. Record the root barrier kind for the first encountered total barrier to root penetration.

(0)	None	(6)	Lithic contact
(1)	Paralithic contact	(7)	Duripan
(2)	Fragipan	(8)	Petrogypsic
(3)	Petrocalcic	(9)	Petroferric
(4)	Densic contact	(10)	Continuous orstein
(5)	Placic	(11)	Compacted layer

Rock Fragment Cover Percent. Rock fragment cover is a visual estimate of the percentage of the soil surface occupied by rock fragments within a 10 meter radius around the point. Enter as a narrow range of percent (e.g. 10-15). Enter shape and size rock fragments (See Appendix D.)

Shape-Round Classes		Shape-Flat Classes	
GRF - Fine Gravel	0.2 - 0.5 cm diameter	CN - Channer	0.2 - 15 cm long
GRM - Medium Gravel	0.5 - 2.0 cm diameter	FL - Flagstone	15.0 - 38 cm long
GRC - Coarse Gravel	2.0 - 7.6 cm diameter	STF - Stone	38.0 - 60 cm long
CB - Cobble	7.6 - 25.0 cm diameter	BYF - Boulder	> 60 cm long
ST - Stone	25 - 60.0 cm diameter		
BY - Boulder	> 60 cm diameter		

Profile notes: Provide other information that may be important in verifying how well the soil component fits the mapping unit. If the soil component would normally be identified as this soil or as a similar soil, verify that the soil component name is correct. Information such as mottling and soil profile drainage can be included.

SOIL QUALITY EVALUATION - NEAR SURFACE SOIL PROPERTIES are used in soil quality evaluation. Several properties within a 30 cm depth (mini-soil pit) are used. The features considered are:

(1) Soil properties and conditions (%clay, water state)
(2) Soil structure
(3) Resistance of the soil mass to rupture
(4) Evaluation of the least permeable zone
(5) Soil chemistry (pH, EC, OM)
(6) The expression of crust

NEAR SURFACE MORPHOLOGY. Subdivide the 30 cm profile into horizons or zones of properties that might change permeability. Start at the soil surface and measure down.

Depth is entered as the upper and lower depth in centimeters.

Horizon notation should correspond with normal horizon nomenclature in the Soil Survey Manual.

Field percent clay is the percentage of clay in the horizon as determined by field texturing.

Water state is the field moisture state as sampled. The classes are:

(1) D - Dry
(2) SM - Slightly moist
(3) MM - Moderately moist
(4) VM - Very moist
(5) W - Wet

Structure -. Structure evaluation for the near-surface morphology will use grade, size, and shape criteria. It relates to thickness, infiltration, and permeability behavioral characteristics (micro-horizons) of the soil.

Grade of structure is: (ignore if massive or single grain)

(1) Weak
(2) Moderate
(3) Strong

Size of structure is:(ignore if massive or single grain). (If the *shape* is platy (pl), see next section, the size descriptive name is different but the code id is the same (vf, f, m, c, vc).

		(If platy)
vf	Very fine	Very thin
f	Fine	Thin
m	Medium	Medium
c	Coarse	Thick
vc	Very coarse	Very thick

Shape of structure is:

gr - Granular	pr - Prismatic
sbk - Subangular blocky	cpr - Columnar
abk - Angular blocky	m - Massive
pl - Platy	Sg - Single grain

Moisture rupture resistance is the rupture resistance of block-like specimens.

(1) L - Loose
(2) VFr - Very friable
(3) Fr - Friable
(4) Fi - Firm
(5) FVi - Very firm
(6) EFi - Extremely firm

EC - This data field is optional for characterization of soil health. See EC section on page 28

pH (Reaction) -This data field is optional for characterization of soil health. See EC section on page 28

OM - Organic Matter is the weight of decomposed plant and animal residue and is expressed as a weight percentage of the soil material less than 2 mm in diameter (e.g. 0.5-1.5). The organic matter will be determined by a lab test from samples taken from the field (Optional data).

ZONE OF MAXIMUM BULK DENSITY IN UPPER 30 CM. Probe with a knife or other instrument to determine the zone of greatest resistance (bulk density). Use spade soil slice to determine soil structure indicators of compaction. This measurement will be taken at mini-soil pit site.

Upper depth is the distance from the surface of the soil to the upper boundary of this zone.

Lower depth is the distance from the surface of the soil to the lower boundary of this zone.

An optional measurement of bulk density identification may be taken at other microtopographical positions in the proximity of the primary soil sample site. This would be conducted only on selected PSU points with specific sampling instructions.

CRUST DESCRIPTION - Crust expression is described with crust type, color, thickness, dry rupture resistance, and family particle size class.

Crust type is (0) none, (1) biocrust, or a (2) mineral crust. Biocrusts are sometimes described as cryptogam cover and are composed of moss and lichen. These crusts indicate long stability of the site and occur only on pasture, range, or forested sites that have not recently burned. Mineral crusts can occur on any land cover and are important for infiltration of water and emergence of seedlings.

Dry surface color is the hue, value, and chroma of the dry surface of the crust. Surface color is important to determine albedo or reflectance of the surface for erosion modeling. The square of the color value is used as an estimation. Reflectance is important in energy transfer. If the soil surface is wet, record not applicable (N/A).

Thickness of crust is measured. Measurement should be made for the distance from the top of the crust to where the massive conditions disappear. Crust

thickness is important to understand the resistance to rupture. Enter thickness classes:

	mm
(1)	0-2
(2)	2-8
(3)	8-20
(4)	20+

Crust material particle size is the soil taxonomic family classes of (1) sandy, (2) loamy, or (3) clayey. It is used in conjunction with crust thickness and dry rupture resistance to evaluate the significance of the crust for its effect on infiltration of water and emergence of seedlings.

Dry rupture resistance class of platy is a descriptive classification of the resistance of the crust to pressure. The specimen should be 10 to 15 mm on edge and 5 mm thick or the thickness of occurrence if less than 5 m. Surface crust thickness is inclusive of the crust proper and the adhering soil material beneath. The specimen is grasped on edge between extended thumb and first finger. Force is applied along the longer of the two principal dimensions. Force exerted is calibrated with the set of springs provided and placed into the following classes.

Classes		Force in Newtons
(1)	Weak	Removable, <1 to 3
(2)	Moderate	3 to 20
(3)	Strong	20 to 80
(4)	Extremely strong	≥80
(5)	Too wet to determine	

AGGREGATE STABILITY. Aggregate breakdown relates closely to infiltration and erodibility. If soil aggregates are unstable during a rainfall event, decreased water infiltration results, due to partial blocking of pores with aggregate particles.

Measurement of aggregate stability and strength (soil aggregates and crusts) will be determined by a slake test.

Soil stability will be determined on soils from three strata: bare soil, grass, and shrub and correlated to microtopographical positions. Soils will be sampled at random along vegetation transects.

Soil will be tested from both the upper surface (0-1/4") layer and from just below the surface (3/4-1").

These two measurements respectively will provide an indication of (1) current stability and (2) potential future stability following crust disturbance. The slake test should be done only on air-dry soils as moist soil will tend to overestimate relative stability. Soil stability should be measured on soil fragments, 6-8 mm in diameter and 2-3 mm thick

Soil stability is rated according to the time required for the fragment to disintegrate during the 5-minute immersion (classes 1-3) or the proportion of the soil fragment remaining on the mesh after the three extraction-immersion cycles (classes 4-6).

Criteria for assignment of soil slake class are based on (1) the time taken for 50% or more of the soil segment to disintegrate when inserted into deionized water (classes 1-3) or (2) if no disintegration has occurred by 300 seconds (5 minutes)the % soil remaining on the sieve following three slow extraction-reinsertion cycles (classes 4-6). Soil which is too unstable to permit sampling is assigned slake class 1.

Slake Class (Stability Class)	Criteria for Assignment to Slake Class
1	50% of soil structure lost within 5 seconds of insertion in water.
2	50% of soil structure lost between 5-30 seconds after insertion.
3	50% of soil structure lost between 30-300 seconds after insertion.
4	0-25% of soil remaining on sieve after 3 dipping cycles.
5	>25-75% of soil remaining on sieve after 3 dipping cycles.
6	>75-100% of soil remaining on sieve after 3 dipping cycles.

Slake Test Field Sampling Procedures. Use Soil Quality Test + Sampling form (Illustration 10) To recorded information on aggregate stability.

1. Identify, and rank the vegetation strata. All areas of plot must fit into one strata. Strata must be ranked. Points with overlapping strata assigned strata with highest rank. Standard; g-grass/s-shrub/t-tree/b-bare

2. Place pin flags, 3 feet from the vegetation transect line on the opposite side of the production plots at distances noted on table 1 (0, 20, 40, 60, etc.) Record

the Vegetation Strata and Microtopographic Unit at each of the 16 points. Avoid trampling points. .

Vegetation strata
S - Shrub
G - Grass
B - Bare
O - Other_____

Microtopo Units
1. Coppice
2. Coppice bench
3. Intercoppice
4. Terracette Playette
5. Other_____
6. None

Table 1

Transect	Distance	Vegetation Strata	Microtopo Unit	0 - 5 mm			20 - 25 mm		
				Start	Sieve	Class	Start	Sieve	Class
1 (N-S)	0			0:00	5:00		2:00	7:00	
1	20			0:15	5:15		2:15	7:15	
1	40			0:30	5:30		2:30	7:30	
1	60			0:45	5:45		2:45	7:45	
1	90			1:00	6:00		3:00	8:00	
1	110			1:15	6:15		3:15	8:15	
1	130			1:30	6:30		3:30	8:30	
1	150			1:45	6:45		3:45	8:45	
2 (W-E)	0			0:00	0:50		2:00	7:00	
2	20			0:15	5:15		2:15	7:15	
2	40			0:30	5:30		2:30	7:30	
2	60			0:45	5:45		2:45	7:45	
2	90			1:00	6:00		3:00	8:00	
2	110			1:15	6:15		3:15	8:15	
2	130			1:30	6:30		3:30	8:30	
2	150			1:45	6:45		3:45	8:45	

3. Return to each pin flag and collect a small aggregate sample from the surface (0-5 mm) and sub-surface (20-25 mm) for soil stability test. Place in the dry baskets in appropriate cells in the slack test sample box. Always use the first sample collected. Do not collect surface (0-5 mm) samples when the pin flags fall on rock, litter or moss. When this occurs record the appropriate code in place of the stability class:

R= Rock (0-5 and 20-25 mm). For bed rock

L=Litter (0-5 mm) for strongly developed O horizon (litter is stable with respect to wind and water)
M=Moss (0-5 mm).

For both Litter and Moss, the 20-25 mm samples should be collected at depths below soil surface.

4. If soil samples are wet, leave boxes open and allow to air-dry for as long as possible. Remove the baskets from slack test sample box. Run stability tests by filling each slot in the slack test sample box with deionized water and then emersing each baskets into its designated slot in the sequence listed on table 1. After 5 minutes, remove each basket (sieve) from the solution and record the stability class on the form.

5. Return to each pin flag and collect two additional soil sample one at depths of 0-2.5 and second at depths of 2.5-10 cm. To collect these samples drive the 3 - inch ring into the soil to a depth of 2.5 cm, and put the soil inside the ring into a plastic ziplock bag. Repeat this procedure with the 2 inch sampling tub to a depth of 10 cm. Soil samples from each point should be combined with other soil samples from the same vegetation strata. Send air-dry soil samples to Al Amen RS140, National applied Resources Sciences Center, building 50, Denver Federal Center, P.O. Box 25047, Denver , Colorado, 80225-0047. Be sure to include the following information on the bags; PSU, and point number, vegetation strata, and soil depth (0-2.5, or 2.5-10).

SOIL SAMPLING - Sampling for reference purposes, Field Test Analysis and/or Possible Future laboratory analysis (for selected sites or all sites).

Sample Depths - Procedures to be used.

- Soils with a "O" horizon - sample the "O" horizon and the upper 10 cm of the mineral soil.
- All other points are sampled at depths surface layer (1 to 7 cm).

Sample Collection

For the 0-5 cm samples, (surface): Primary sample (equivalent to sample volume/quart):

- Lay the wood board flat on the soil surface and cut along its edges.
- Remove a soil sample of the board thickness (the sample should be equivalent to the volume of the board). Bag and label.

Colorado BLM 1997
Test Pilot Worksheet

PSU NUMBER_ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Page 9

POINT NUMBER ☐ SITE 1 or 2 (CIRCLE)

SOILS INFORMATION

SOILS TRANSECT SOIL QUALITY TEST + SAMPLING
Distance from transect line_____(ft)

Transect	Distance	Cover Strata	Microtopo Unit	0 - 5 mm			20 - 25 mm		
				Start	Sieve	Class	Start	Sieve	Class
1 (N-S)	0			0:00	5:00		2:00	7:00	
1	20			0:15	5:15		2:15	7:15	
1	40			0:30	5:30		2:30	7:30	
1	60			0:45	5:45		2:45	7:45	
1	90			1:00	6:00		3:00	8:00	
1	110			1:15	6:15		3:15	8:15	
1	130			1:30	6:30		3:30	8:30	
1	150			1:45	6:45		3:45	8:45	
2 (W-E)	0			0:00	0:50		2:00	7:00	
2	20			0:15	5:15		2:15	7:15	
2	40			0:30	5:30		2:30	7:30	
2	60			0:45	5:45		2:45	7:45	
2	90			1:00	6:00		3:00	8:00	
2	110			1:15	6:15		3:15	8:15	
2	130			1:30	6:30		3:30	8:30	
2	150			1:45	6:45		3:45	8:45	

Cover * Strata (Ranked by preference)

(1)_____

(2)_____

(3)_____

(4)_____

*all area of plot must fit into one strata. Strata must be ranked. Points with overlapping strata assigned strata with highest rank. Standard;grass/shrub/tree/bare

Microtopo Units
1. Coppice
2. Coppice bench
3. Intercoppice
4. Terracette Playette
5. Other_____

Class	Criteria for assignment to stability class
0	Soil to unstable to sample (fall through sieve)
1	50% of structual integrity lost within 5 seconds of insertion
2	50% of structual integrity lost within 5- 30 seconds after insertion
3	50% of structual integrity lost within 30- 300 seconds after insertion
4	0-25% of soil remaining on sieve after 5 dipping cycles
5	>25-75% of soil remaining on sieve after 5 dipping cycles
6	>75-110% of soil remaining on sieve after 5 dipping cycles

For microtopographical position soil samples:

Soil samples representing specific microtopographical positions will be taken at depths of 0-5 cm with a core sampler. Volumes of samples for each topographical position would be 1 pmt (480 ml), and placed in plastic heavy-duty freezer bags (1 quart capacity) and labeled.

For special soil samples:

Special soil samples for specific selected sites may be taken for testing protocols. Specific instructions and sites will be identified.

- 5-15 cm depth soil sample
- zone of highest bulk density within 30 cm profile

Bagging and Labeling Soil Samples:

- Place soil samples in plastic heavy-duty freezer bags (1 gallon capacity). Avoid unnecessary crushing of samples.
- Label on the ID block on the plastic bag with black permanent marker pen the following information:

  FIPS CODE _____; PSU ID _____; Sample Point No. _____; Depth: _____ to _____ centimeters; Date: _____; Initials: _____.

RANGELAND

TRANSECT LAYOUT

Align a 150 ft tape on a North-South bearing with the 75 foot mark at the Sample Point. This will become transect 1. The beginning of transect 1 will be at the north end of the tape. For Transect 2 align a second 150 ft tape on an East-West bearing with the 75 foot mark at the Sample Point. The beginning of transect 2 will be at the west end of the tape. See Figure 1.

Five weight estimate plots will be located along each transect with the edge of each plot adjacent to the tape. Plots on transect one will be on the west side of the tape and plots on transect 2 will be on the south side of the tape. Plots 1- 5 will be (Transect 1) at the 12.5 ft, 37.5 ft, 62.5 ft, 112.5 ft, and 137.5 ft marks on the tape. Plots 6- 10 will be located on Transect 2 at the 12.5 ft, 37.5 ft, 87.5 ft, 112.5 ft, and 137.5 ft marks on the tape. All foot traffic along the transect should

Inventories-Database
Modeling-GIS

Applications of GIS in Soil Quality/Health Evaluation

Soil degradation attribute data in a GIS consist of discrete observations or measured parameters recorded while digitizing maps or estimated from the combination of other spatial parameters contained in an existing data base. The application of GIS to soil quality/health assessments has been in the areas of analysis and display of relevant attribute data, the parameterization of simulation models, and the linkage of GIS with these models. A flow chart summarizing data sources, inputs and results of GIS analysis, and different steps of data manipulation is present in Figure 1.

A. Sources of Spatial Data

Current sources of spatial data for quality/health evaluations consist of 1) digitized soil maps that provide data on soil erodibility, permeability, water retention properties, texture and structure, etc., 2) topographic maps and DEMs from which water shed geometric properties (slope gradient, slope aspect, shaded relief, flow paths, etc.) and drainage network characteristics (drainage density, stream order) are extracted, and 3) aerial photographs, land cover/land use maps or remote sensing data from which land cover classes can be derived (Burrough, 1989). The use of remote sensing images as sources of land cover/land use information for soil degradation assessments has been discussed by Nizeyimana and Petersen (1996).

Soil maps from which GIS data can be derived are prepared manually from county soil survey reports. The process is difficult and expensive, and boundaries between map units in soil survey reports are often inaccurate. Today, the process of digitizing soil delineations based on orthophoto quadrangles and the building of related attribute data are used to correct these inaccurate mapping unit boundaries and to perform better data management. The Natural Resources Conservation Service (NRCS) has established the Soil Survey Geographic (SSURGO) data base to be used primarily for natural resource planning and management at the farm and county level (U.S. Department of Agriculture, 1995). Digital soil survey maps of SSURGO are made by digitizing soil delineations using orthophoto quadrangles as map bases at scales ranging from 1:12,000 to 1:62,500. The soil attribute data are entered into the data base using records from county soil survey reports.

Recent advances in GIS applications have promoted the development of technologies and spatial data bases that will enhance soil degradation monitoring and assessments. Some of these are the Global Positioning Systems (GPSs) and Digital Orthophoto Quadrangles (DOQs). GSP allows the user to record accurately soil and terrain attributes observed or measured, then be input into a GIS along with their precise location. GPSs couple with a GIS can improve the accuracy of soil degradation mapping by increasing the spatial variability of soil attributes.

B. Digital Thematic Maps

Soil quality/health data may consist of discrete observations or measured parameters derived from digitizing soil maps. For example, a GIS representation of soil pH, organic C, water holding capacity, and texture can help locate the most degraded areas in a field or watershed. Although individual properties provide valuable information, they may not be enough to explain differences in soil quality/health. Therefore, a GIS assessment of soil degradation often involves the integration of attribute data from different types and sources. This approach consists of map

overlays of variable layers and analysis of attribute data to derive soil degradation potential classifications. For example, an interpretative digital layer showing the distribution of soil degradation hazard classes can be created by combining soil properties (texture, structure, organic C content, etc.), vegetation (land use/land cover), and slope. A typical example was provided by the Sagers Wash Watershed analysis where erosion class maps were created by overlaying different layers of parameters derived from soil and topographic maps, Landsat TM imagery, and GPS-recorded coordinates.

C. Hydrology/Water Quality Modeling

1. Parameterization of Erosion Models

Research has been conducted to establish mathematical relationships between various soil, landscape and vegetation features and the rate of soil degradation. The most well-known example is the Revised Universal Soil Loss Equation (RUSLE).

The simplicity of the equation and the spatial variability shown by its parameters make it well-suited for use in a GIS. The variables of land cover, soil, slope gradient and slope length are first translated into classes of C, K, S, and L factors, respectively, for each mapping unit or grid cell. The R and p factors are usually set to constants in these kind of studies. A digital map showing the distribution of long-term average soil loss in the watershed in then created by overlaying GIS layers of these parameters. Reference is made to the Sager Wash Watershed analysis where GIS layers of classes of L and S factors were generated from DEMs, C factor from Landsat TM, and K factor from soil maps, and used them in the RUSLE equation to create a map of soil erosion rates.

The GIS parameterization of soil water erosion models, other than the RUSLE, has also been accomplished.

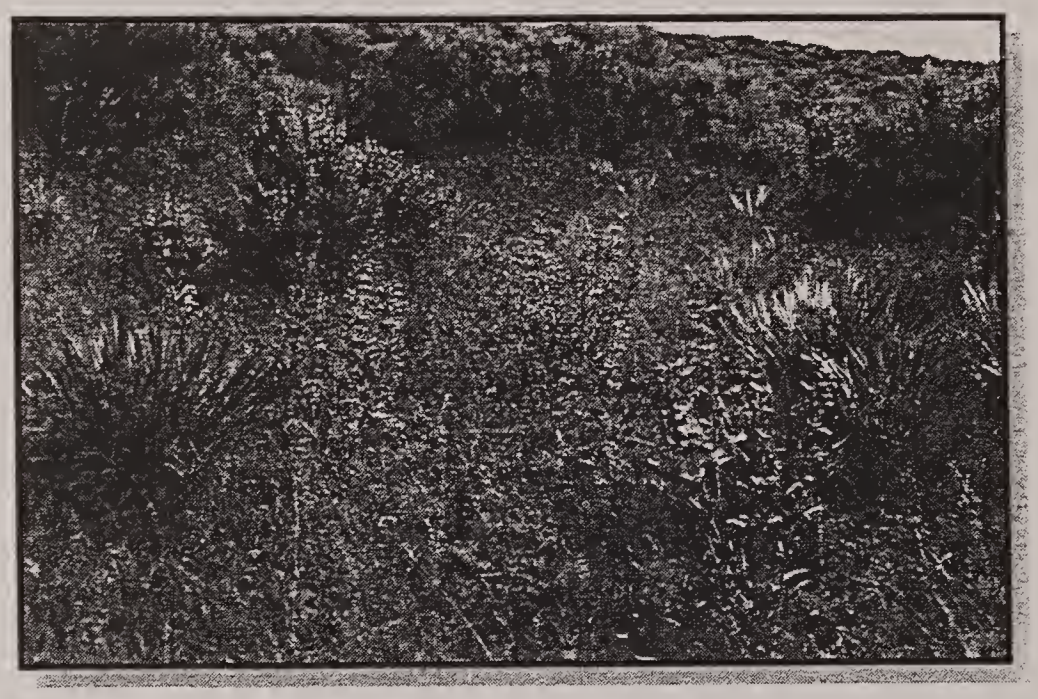
Interpreting Indicators of Rangeland HealtH
Draft Handbook

An Educational and Evaluation Tool

April 1998

PREAMBLE/DISCLAIMER

This document is a "work in progress" and is subject to change and modification upon further review by the interagency team that developed it and additional peer review. A final handbook will be released in June (tentative). In the interim use this draft handbook as a "guide" in interpreting indicators of rangeland health for educational and evaluation purposes.



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INTERPRETING INDICATORS OF RANGELAND HEALTH

I. Introduction

The science of monitoring and evaluating rangelands is changing as concepts and protocols continue to evolve. Recently the concept of "rangeland health" was advanced by a panel assembled by the National Research Council as an alternative to the range condition e.g. ecological status concept currently used by most range professionals as the basis for inventory and monitoring. The National Research Council (1994) publication, "Rangeland Health, New Methods to Classify, Inventory, and Monitor Rangelands" defines rangeland health as,

> ***"the degree to which the integrity of the soil and ecological processes of rangeland ecosystems are maintained"***

The challenge to scientists and managers is to translate this concept that involves complex ecological processes and functions into terms that the public can comprehend and that resource specialists can use to assist in identifying landscape units where ecological processes are not properly functioning. This document describes a process to educate and train the public and agency personnel on using indicators to interpret and evaluate rangeland health of selected landscape units. This process relies on the use of a qualitative procedure by an interdisciplinary team to evaluate the functional status of selected rangeland health indicators.

A. Background

The use of qualitative information (e.g. subjective data) to determine range and soil conditions has a long history of use in land management inventory and monitoring. Early procedures that used indicator ratings (e.g. a "scorecard approach") include the "Interagency Range Survey of 1937", Deming Two-phase and Parker Three-Step Methods that determined, among other things, "site-soil stability" and usefulness of forage for livestock grazing (Wagner 1989). The Bureau of Land Management also used "soil surface factors" to determine erosional status of large acreages of public lands in the 1970's (USDI 1973). In 1993, the BLM published a Technical Reference (TR 1737-9) that utilized a qualitative checklist to assess the functioning condition of riparian areas (USDI 1993).

This draft handbook incorporates concepts and materials from previous monitoring and inventory procedures as well as from the National Research Council's book on Rangeland Health (Committee on Rangeland Classification 1994) and the Society for Range Management's Task Group on Unity in Concepts and Terminology. An Interagency Team melded these concepts and results from numerous field tests to arrive at the process described herein. Along the way this procedure has been termed "rapid assessment", "qualitative assessment of rangeland health" and "visualization of rangeland health". This document refers to this procedure as **"Interpreting Indicators of Rangeland Health"**.

B. What is Rangeland Health?

The NRC definition of rangeland health has already been presented. This definition has been paraphrased as, "The degree to which the integrity of the soil, vegetation, water and air as well as the ecological processes of the rangeland ecosystem is balanced and maintained." Integrity is defined as the maintenance, including normal variability, of the structure, organization and function of a landscape unit over time. Ecological processes include the **water cycle** (the capture, storage and release of precipitation) **energy flow** (conversion of sunlight to plant then animal matter) and **nutrient cycling** (the flow of nutrients such as nitrogen and carbon through the physical and biotic environments). Ecological processes functioning within a normal range of variation will support appropriate kinds and proportions of flora and fauna. Regardless of how the term rangeland health is defined the end product is an ecological system that is capable of sustaining the capacity of rangelands to satisfy values and produce commodities.

Direct measures of the site integrity and efficiency of the ecological processes is difficult due to the complexity of the processes and their interrelationships. Therefore, vegetation attributes are often used as indicators of the functional status of ecological processes.

C. Purpose

The purpose of this handbook is to present a procedure that can be used to explain the concept of rangeland health to anyone interested in managing or participating in the management of rangelands. This process identifies a set of indicators and descriptors that can be used to recognize signs of healthy and unhealthy rangelands. The physical e.g. non-living environment is evaluated separately from the biotic or living environment. The better that people understand and can constructively communicate about rangeland health issues, the easier it will be to resolve differences. Therefore, this procedure is best used as a **communication tool.**

For resource specialists, the process provides a format to assist in interpreting and evaluating rangeland monitoring or inventory data. The procedure can also be used to provide a preliminary evaluation of the health of a landscape unit. The results of this evaluation could indicate that additional monitoring may be needed or if combined with quantitative data that a rangeland health problem exists. This application may be used in the determination process for implementing **Standards for Rangeland Health.**

The process is not intended to replace quantitative monitoring studies, be aggregated into regional or national reports or be used to establish trend (either apparent or long term trend).

II. Concepts

The concepts of indicators, ecological reference areas, interdisciplinary teams, and areas of application are essential to this process to evaluate rangeland health using a qualitative rating procedure.

A. Indicators

Unfortunately ecological processes are difficult to observe or monitor in the field due to the complexity of most rangeland ecosystems. To characterize the health status of a selected landscape, indicators are used to assess the condition of selected plant and physical environment attributes. An indicator is a component of a system whose characteristics (presence or absence, quantity, distribution) are used as an index of those attributes that are too difficult, inconvenient, or expensive to measure. Just as the Dow Jones Index is used to gauge the strength of the stock market so are the physical and biotic indicators used to gauge the health of selected landscape units. Each indicator is followed by three descriptors that the interdisciplinary team reviews prior to selecting the appropriate category (plus, intermediate and minus) for each respective indicator.

Indicators have always been a part of the monitoring of rangelands. Historically, resource inventories and monitoring by land management agencies focused on vegetation attributes (production, composition, density, etc) and soil stability as indicators of the condition of rangelands. Such assessments are inadequate to determine rangeland health because they do not reflect nor evaluate the complexity of the ecosystem. There is no one indicator of ecosystem health; instead a suite of key indicators should be used for an assessment (Karr 1992).

B. Ecological Reference Areas

Before assessing the health of specific landscape units, some understanding of the structure, function, and dynamics of the local landscape is required. It is also important to consider that healthy rangelands are variable and that a number of stable states may exist for each ecological site. To obtain this understanding, the interdisciplinary team selects and utilizes Ecological Reference Areas (ERA) for training and as comparison areas for site evaluations. An ERA is a landscape unit in which ecological processes are functioning and the vegetation complex has adequate resistance to and resiliency from major disturbance. This concept is similar to that proposed by the Western Regional Research Coordinating Committee-40 on Rangeland Research of using well-managed rangelands and appropriate relict areas on given ecological sites as benchmarks for assessments (Range Improvement Task Force 1994).

Sources to assist in the identification of potential ERA's include:

1. Ecological Site Descriptions
2. Soil Surveys
3. Ecological or the older Soil-Vegetation Inventory Method Inventories
4. Research Natural Areas, Wilderness Study Areas or other protected/special managed areas
5. Use pattern maps (lightly used areas) and topographic maps
6. Historical records and photographs
7. Well managed rangelands (livestock use is appropriate to maintain ecological processes and the plant community in a proper functioning state)

Once potential ERA's are identified the **entire** Interdisciplinary Team should visit the sites in the field and determine if the criteria for an ERA is met:

1. Site is occupied by a composition of plants found under normal soils, climate, and natural disturbance regimes relative to the site potential.

2. The indicators for the Biotic Integrity and Physical Environment Worksheets are mostly in the "Plus" category. For example, a weed infested area would not be considered a good ERA even if the other indicators were mostly in the "Plus" category.

Ecological reference area where baseline studies are being established.

At each ERA, an interdisciplinary team takes photographs and records baseline information on system attributes and indicator status by completing the range health worksheets and conducting quantitative cover studies. This information is used for training purposes, future comparisons, and developing photo guides for assessment of landscape units with similar site potentials.

There are instances when ERA's are not available for selected ecological sites due to past disturbance and/or weed invasion. In these cases ecological site descriptions should be utilized along with the best available field sites to "reconstruct" the ERA. Historical journals, photographs, similar ecological sites and scientific literature along with knowledge of the area (including the interdisciplinary team and "users" of the land) are other useful tools in the reconstruction process.

Isolated BLM tracts may provide good ecological reference areas

Small exclosures may be a valuable reference point but their value as ecological reference areas may be limited by their small area.

C. Thresholds

Thresholds are boundaries across which plant communities and ecological processes may be "pushed" by natural or human forces. Healthy ecosystems are both *resistant* to external disturbance and *resilient* or able to recover if external disturbances are present. However. if a threshold is crossed the community may exist in a new stable state unable to go back to the previous community until disturbance factors push it back towards its former self or to another different stable state. Once a community is pushed over a threshold that is undesirable. it may be very difficult to restore the original plant community and ecological processes by changes in management alone. It may require more expensive restoration measures (weed control. seeding, etc.) to restore these degraded vegetation states..

D. Interdisciplinary Teams

The use of an interdisciplinary teams is required to properly utilize this procedure to evaluate indicators of rangeland health on landscape units. At a minimum this team should include a rangeland ecologist/conservationist, soil scientist or resource specialist familiar with area soils and soil/vegetation relationships, and a wildlife or habitat biologist. The interdisciplinary team should train together, investigate ecological reference areas and conduct as much of the evaluation together as possible. It is recognized that not all field offices have all of the disciplines adequately represented to conduct rangeland health evaluations. Other agencies may be able to provide these "scarce skills" specialist to train the regular interdisciplinary team members in the areas where expertise is missing. Every effort must be made to insure the use of well staffed interdisciplinary teams in both the evaluation and educational applications of this procedure.

E. Area of Assessment

The assessment area must be large enough to account for the natural variability associated with ecological site being evaluated. Upon arrival at the site, the interdisciplinary team should walk a 1-2 acre area to become familiar with the plant species and the range in variability of the site. The ecological site should be confirmed by reviewing the ecological site description and confirming the soils at the evaluation site. The best way to confirm the soil classification and thus the ecological site is for a soil scientist to dig a small pit to insure the soils classification in the Soil Survey or other source is correct. In lieu of this, the interdisciplinary team should review the site description for consistency with the soils and vegetation found on the site to be evaluated.

F. Lack of Soil Survey or Ecological Site Information

Comparisons between the ecological reference area and evaluation areas is difficult in areas where a soil survey has not been completed and ecological site descriptions have not been developed. Identification of ecological reference areas is hindered and correlations between ecological reference areas and evaluation areas is difficult. Several options can be considered in this situation. First obtain the assistance of a qualified soil scientist to assist the interdisciplinary team in making the initial evaluations.

If a soil scientist is not available and the evaluation must continue, the interdisciplinary team should conduct the evaluation linking similar landscape units (e.g. plant communities) in lieu of using ecological site descriptions. The limitations in conducting an evaluation without the required soils and ecological site information should be clearly described in any use or interpretation of the data.

III. Worksheets

Four worksheets are used to assist the interdisciplinary team in interpreting indicators or rangeland health for educational or evaluation purposes:

1. Cover by plant life form and ground cover for site protection (Appendix 1, **Cover Worksheet**).
2. Dominant species abundance by life form (see Appendix 1 , **Species Abundance Worksheet**).
3. Physical environment status based upon ten indicators (see Appendix 1, **Physical Environment Worksheet**).
4. Biotic integrity status based upon nine indicators (see Appendix 1, **Biotic Integrity Worksheet**).

A **Rangeland Health Site Documentation Worksheet** (Appendix 1) is also completed to record location of assessment, ecological site(s), and other relevant landform features and site uses. The use of each worksheet is now described.

A. Site Documentation Worksheet

This worksheet is used to record information on site location(s) for evaluations and some basic site characteristic information (Appendix 1 & 2). Critical items that must be filled out on this form includes all of the "**bold**" items on the worksheet. As a part of site documentation, either photographs, slides or digital images should be taken and included as an attachment to this form and filed in the appropriate location. Two general view photographs taken in different directions (include some skyline for future point of reference) should be taken along with closeup shots that illustrate important indicator values or anomalies. Photographs are required on ecological reference areas.

B. Cover Worksheet

This is the first worksheet to be completed by the interdisciplinary team after the Site Documentation Worksheet is completed. The Cover Worksheet is divided into a "Vegetation Life Form" section where canopy cover is estimated for important life forms (Grass, Forb, Shrub, Tree, and Succulents) and a "Ground Cover" section where the bare ground and ground cover components are estimated (Appendix 1).

Canopy cover is defined as the percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants.

Small openings within the canopy are included. Canopy cover of plants removed by grazing are **not** reconstructed to pre-grazing canopy for this estimate. Estimate only the canopy cover present at the time of the assessment. Ground cover is the percentage of material (litter, gravel/rocks, vegetation and microbiotic crust), excluding bare ground, covering the land surface.

Training is required to estimate cover in the classes shown on the form. A quick procedure to train inexperienced personnel in estimating cover is the Step-Point Method described in the Interagency Technical Reference entitled, "Sampling Vegetation Attributes" (NARSC 1996).

The subdivisions of life forms under each life form class (e.g. annuals, native perennial, exotic perennial under the I.- Grass category) may be deleted and other categories added to better represent local vegetation. The cover ranges may also be changed to better fit natural breaks in cover for different areas.

The cover in the Vegetation Life Form section includes cover estimates of the overlapping canopies of different life forms. For example, both the cover of grasses beneath the canopies of shrubs are estimated and recorded on the worksheet. The Ground Cover Section is intended to represent the total cover available for site protection, therefore, overlapping cover classes are not recorded. This is accomplished by recording cover estimates of litter, bare ground, rock/gravel, microbiotic crust outside the canopy of vascular plants i.e. in the interspaces. Therefore the sum of these five cover categories should total roughly 100% given the use of ranges of cover instead of discrete cover values on the form.

The total cover of the Vegetation Life Forms will not necessarily equal the Vascular Plants cover value in the Ground Cover Section since the former contains cover estimates for overlapping canopies while the latter does not. The litter category in the Ground Cover section includes both persistent and non-persistent litter. Litter includes all dead organic matter on the soil surface as well as standing dead material that is more than one growing season old. The rock/gravel category includes all material greater than 2 mm long.

Microbiotic Crust includes lichens, mosses, cyanobacteria, and algae that grow on the soil surface. It is difficult to distinguish some forms of microbiotic crust from bare soil or dead organic matter during the dry, hot portion of the summer. Spraying the crust with water from a squirt bottle will often turn live microbiotic crust a greenish tinge indicating live tissue.

The information on the Cover Worksheet is used in the completion of the Species Abundance, Physical Environment and Biotic Integrity Worksheets.

C. Species Abundance Worksheet

The Species Abundance Worksheet is used to record the overall dominant species at the evaluation site and the dominant species by life form. The attribute that the abundance rating is based on is current canopy cover of vegetation. Do not reconstruct canopy cover when determining species abundance if utilization of plants has occurred. It is not necessary to fill each blank in the list of species by life form if dominant species in that life form are not present.

There is also an entry to list all noxious weed species in the evaluation area. This list should be shared with the Field Office noxious weed coordinator if the weed infestation is new. The interdisciplinary team should be able to identify all of the State Listed noxious weeds prior to conducting any evaluations.

Information from the Species Abundance Worksheet is useful in completing the Biotic Integrity Worksheet.

D. Physical Environment & Biotic Integrity Worksheets

The procedure to complete both of these worksheets is the same, therefore they are discussed together. Each indicator on the Physical Environment and Biotic Integrity Worksheets has three "descriptors" representing a functional state for the indicator termed "plus", "intermediate" and "minus". A plus rating means that the indicator is functioning properly relative to site potential. The intermediate category signifies that the indicator is functioning poorly relative to site potential and is "at risk" of crossing the threshold to the "minus" or improperly functioning category. The minus category denotes that the indicator is improperly functioning relative to site potential and that an unacceptable ecological threshold has been crossed

The functional status of each indicator is rated at the bottom of the worksheet by placing the number of each indicator under the appropriate descriptor (plus, intermediate or minus) heading (see Appendix 2 for an example of a completed set of worksheets). Furthermore the relative position of the indicator number can be used to manifest the relative functional status for the particular indicator. For example an indicator on the border between plus and intermediate would signify more of a departure from proper functioning condition than the same indicator placed in the far left position under the plus category. This scale allows placing each indicator rating in the appropriate position under each of the three headings (Plus, Intermediate and Minus).

All indicators should be rated even though there may be no evidence of the indicator within the evaluation area. Place the indicator number in the far left corner under the "Plus" category in this situation. On the back of both worksheets is a comment section for each indicator. This area can be used to explain the rationale for the rating of each indicator or note unusual circumstances or anomalies.

IV. Interpreting Indicators of the Physical Environment

In the physical, i.e., abiotic environment, indicators are used to assess soil and watershed stability. Soil stability and proper watershed function are important because they promote normal capture, storage and release of water. Information on the Cover Worksheet should be reviewed prior to completing this worksheet Indicators of soil and watershed condition are listed in the attached Physical Environment Worksheet (Attachment 1) and are now described in more detail:

1. Litter Movement. The degree and amount of litter distribution is a good indicator of the stability of the site and degree of wind and/or water erosion. The redistribution of litter within a small area on site is less indicative of functional problems than is the movement of litter off the site due to wind or water movement. The size of litter moved by wind or water can also be used as an indicator of degree of redistribution. In general the greater distance that litter is moved from its point of origin and the larger the size and amount of litter moved, the greater the site is being influenced by erosional processes relative to site potential for erosion. stability.

Indicator	Plus	Intermediate	Minus
2. Surface Litter	In place or slight movement	Moderate movement, bigger litter displaced	Extreme movement, occurs with each event

Figure Combination of vascular plant and microbiotic crust provides good ground cover and reduces the potential for litter movement (Plus).

Litter is accumulating in flow pattern indicating inadequate ground cover (Intermediate).

2. Soil Movement-Water. Accelerated soil movement by water occurs when the rate of infiltration is reduced beyond that expected for the reference state. Reduced ground cover and increased soil compaction are the primary agents responsible for this type of accelerated soil movement. Soil movement is evaluated by looking for the presence of terracing ("benches" caused by erosion or deposition of soil) and plant or rock pedastalling caused by moving water. Soil deposition areas are another sign of water induced soil movement. As the degree of soil movement by water increases pedastal heights increase exposing plant roots, terraces are higher and deposition areas are larger. Plant or rock pedastals caused by frost heaving must be identified and not counted as erosional pedestals.

Indicator	Plus	Intermediate	Minus
3. Soil Movement-Water	None to slight	Moderate, slight terracing & some short pedastals	Significant movement with each event, rocks and plants on pedastals, some roots exposed

Flow pattern contains gravel relocated in the course of water movement across the landscape (Minus).

Significant soil and gravel movement has occurred from uplands above this area (Minus).

Pedastalled Sandberg bluegrass caused by water erosion (note exposed roots)(Minus).

Soil terrace caused by water slowing down at flow impediment (sagebrush stem) (Minus).

3. Soil Movement-Wind. Accelerated wind erosion is present when the presence of wind scoured depressions and aeolian (wind) deposits on the leeward (opposite side of plant or other obstruction from prevailing wind direction) side of plants, persistent litter, rocks, etc increases over that evident in the ecological reference area or relative to site potential for soil movement by wind. Extreme evidence of wind erosion is the formation of dunes of sand or soil caused by excessive soil movement. Generally wind erosion is a greater problem on sandy soils and is closely correlated to ground cover. Wind erosion can also cause pedastalling of rocks and plants.

Indicator	Plus	Intermediate	Minus
4. Soil Movement-Wind	None to slight	Wind scoured depressions evident, small aeolian deposits around plant clumps	Wind scoured depressions common with large aeolian deposits around plant clumps

Loss of ground cover has increased wind erosion as noted by the wind scoured depressions and litter redistribution (Minus).

Soil movement by wind has caused this small rock to be pedastalled (Minus).

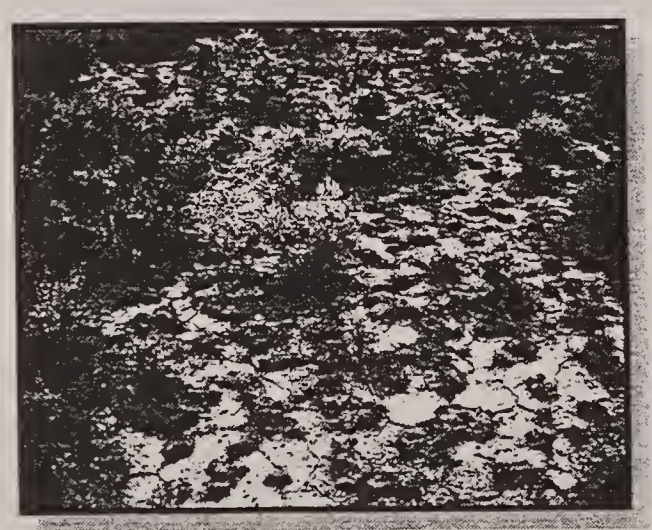
4. Physical/Chemical Soil Crusts. Physical soil crusts (does not include microbiotic crusts) are caused by the impact of raindrops on bare soil causing the soil surface to "seal" and absorb less water. As this physical crust becomes thicker and more extensive, infiltration rates are reduced and overland flow increases. Water tends to pond in the crusted areas and is more likely to evaporate than infiltrate into the soil. Physical soil crusts are identified by breaking the soil surface with a pen or other sharp object and determining the depth of the crusting and size of the crust unit that is cohesive. The amount of physical crusting is directly related to the amount of bare ground and the type of soil. Crusting is more likely to occur on clayey or silty soils than on loamy or sandy surface soils.

Chemical crusts are less common than physical crusts and are found on soils with high salt content. The amount of chemical crusts are dependent on the type of soil and management actions. It may be difficult to separate the effects of natural chemical crusts from the accelerated crusts caused by management actions.

Indicator	Plus	Intermediate	Minus
5. Soil Crusting & Surface Sealing	None to minimal with "soft" physical and/or chemical crusts	Physical and/or chemical crusting obvious with reduced infiltration occurring	Hard physical and chemical crusts widespread on bare ground, strongly reducing infiltration

This is a "living crust" (e.g. microbiotic crust) that enhances infiltration (Plus).

Closeup of a physical soil crust caused by raindrop impact that inhibits rainfall infiltration (Intermediate).



Bare interspace areas have a well developed physical crust that reduces infiltration and increases overland flow of water (Minus).

5. Compaction Layer. A compaction layer is a sub-surface layer of compacted soil caused by the repeated impacts of herbivore trampling or recreational traffic. This compacted layer usually occurs on finer textured soils, not sandy soils, and is usually 4-12 inches below the soil surface. It is detected by digging a small hole (generally less than one foot deep) with the determination of a compaction layer (e.g. the soil structure change) done by an experienced soils person.

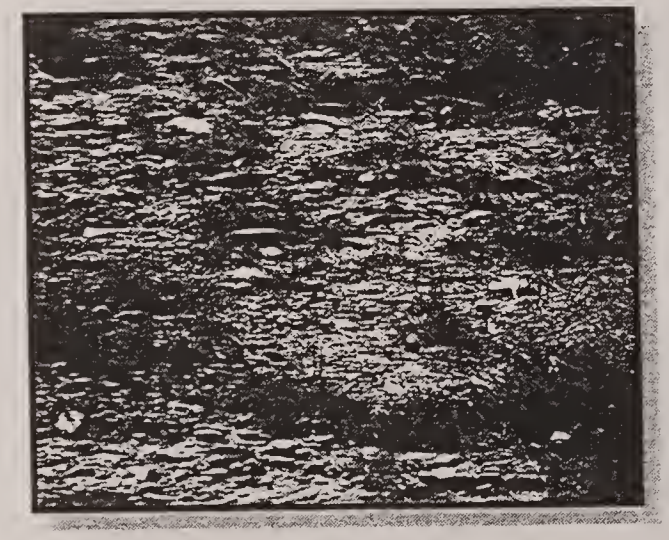
Indicator	Plus	Intermediate	Minus
6. Compaction Layer	None to minimal, not restrictive	Thin, weakly restrictive to roots and water	Extensive with > 1" width, strongly restrictive

Compaction layer (below knife blade) restricts water percolation and root growth (Minus).

6. Flow Patterns. Flow patterns are the path that water takes as it moves across the soil surface. They are generally evidenced by litter, soil or gravel redistribution or pedastalling in the water flow paths. They are controlled in length and coverage by the number and kinds of obstructions to water flow provided by basal intercepts of living or dead plants, microbiotic crust or rocks. Generally, as slope increases and plant and/or gravel/rock cover decreases flow patterns increase.

In a poorly functioning state, flow patterns are well defined and extensive indicating reduced infiltration and considerable overland flow of water (photo here). Shorter lengths of flow patterns with more obstructions indicate less water movement and a system with fewer problems (photo here). These ratings are made against the standard of the reference state and the amount of naturally occurring flow patterns present in the system in a functioning state.

Indicator	Plus	Intermediate	Minus
1. Flow Patterns	Few, slight deposition	Well defined, small with intermittent deposits	Numerous with soil deposits common



Water flow is dispersed by rocks and some vegetation resulting in a short flow pattern with small deposits (Intermediate).

The landscape is one big flow pattern with the shrubs the only impediment to water flow (Minus).

7. Rills

Rills are small rivulets that are generally linear and do not necessarily follow the microtopography as flow patterns do. The potential for rills increase as degree of disturbance (loss of cover) and slope increases. Generally as the distance between rills decreases and depth and width of rills increase the erosional problems are increasing (Photo here).

Indicator	Plus	Intermediate	Minus
7. Rills	If present, rare and widely spaced	Occasionally present, < 3'' deep	Very common at 5' or less intervals, up to 6" deep

Short rill that is somewhat controlled by the vegetation present (Plus).

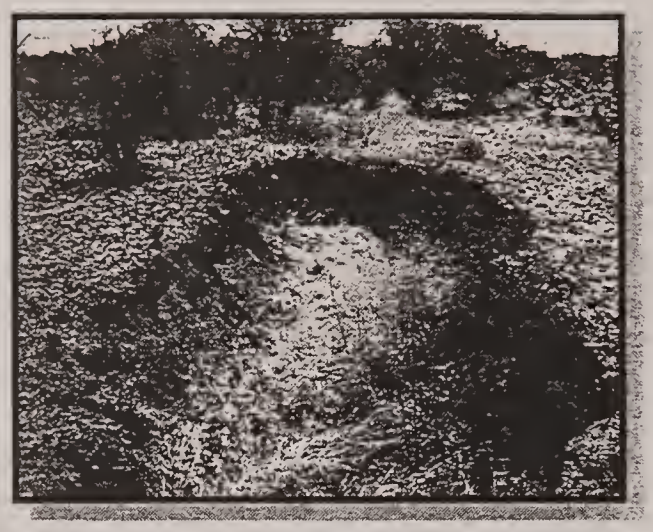
Extensive rilling on denuded slope. Without knowledge of site potential is not wise to call these rills evidence of accelerated erosion.

8. Gullies

A gully is channel that has been cut into the soil by the action of moving water. Gullies generally follow the natural drainages and are caused by the accelerated water flow and the resulting downcutting of the soil. Gullies are a natural feature of some landscapes while on others management actions (excessive grazing, recreation vehicles or road drainages) may cause gullies to form or expand (Mt photo here).

Gullies may be evaluated by observing the amount of gully formation in an area or evaluating the severity of erosion on individual gullies. Generally more signs of active erosion e.g. incised sides along a gully are indicative of a current erosional problem while a healing gully is characterized by "rounded" banks and vegetation growing in the bottom and on the sides. Headcuts (AZ photo here) are a sign of accelerated erosion in a gully even if the rest of the gully is showing signs of healing.

Indicator	Plus	Intermediate	Minus
8. Gullies	None to few, if present gullies are healing (veg. on sides & bottom	Few present, active erosion (incised sides) on < 10% of length	Numerous with active erosion on 20% or more of length, some headcutting evident



Gully is healing on sides but still has active headcut (Intermediate).

Extensive gullies on landscape with evidence of active erosion still occurring (Minus).

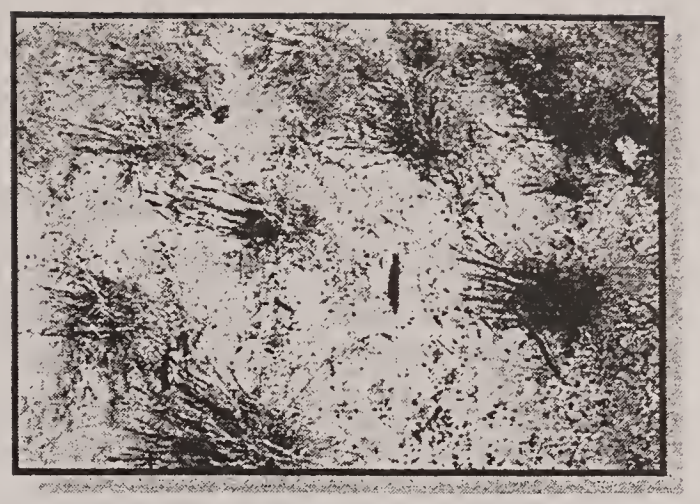
9. Cover- Amount

Ground cover is that percentage of the ground surface covered by vegetation, litter, gravel/rock, microbiotic crust (lichen, mosses, and algae) e.g. everything except bare ground. The amount of ground cover is one of the most important indicators of site stability as indicated by sedimentation relationships to loss of ground cover (diagram here). The amount of ground cover is a direct indication of site protection while the preceding indicators generally indicate the consequences of loss of adequate cover for site protection e.g. they are indirect measures of the loss of cover.

The determination of adequacy of ground cover is made by comparing the expected ground cover for a site as determined by the ecological site description (if it contains ground cover information) and/or at the ecological reference area(s). A comparison of ground cover between the ecological reference(s) area and the site being evaluated is accomplished using the Cover Worksheet. These cover values are considered in concert with the evidence of accelerated erosion to make a determination of this indicator.

Indicator	Plus	Intermediate	Minus
9. Cover-Amount	Adequate (>X %) to protect site from accelerated erosion.	Marginal (around X %) for site protection, accelerated erosion starting	Inadequate (<X %) for site protection, accelerated erosion evident

Adequate ground cover relative to site potential (ecological reference area to protect site from accelerated erosion (Plus).

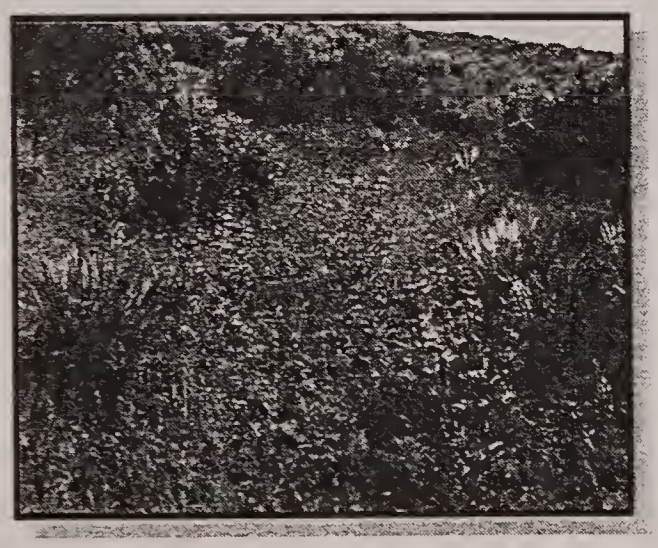


Inadequate ground cover relative to site potential to protect site from accelerated erosion or the proper functioning of ecological processes. (Minus).

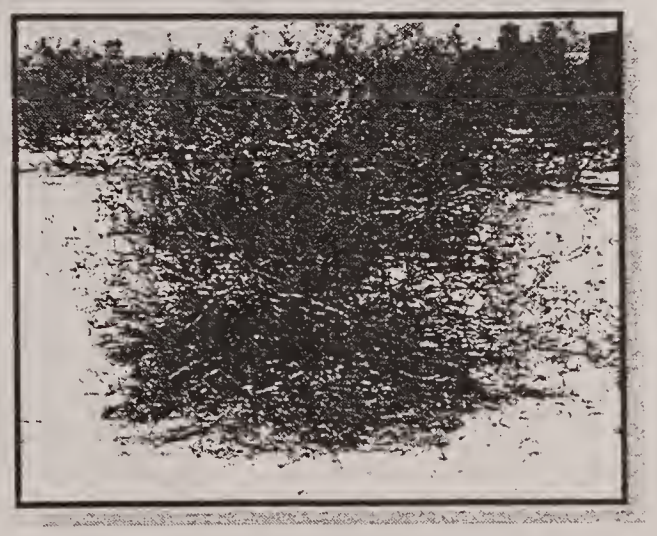
Cover- Distribution

The distribution of cover, not just the amount of cover, is both hydrologically and biologically important. As the size of bare patches increase relative to the site potential, the potential productivity and actual amount of erosion can increase. Also soil organisms are not as likely to be found in unvegetated areas which affects the nutrient cycle and energy flow. As bare patches increase, erosion indicators such as flow patterns, wind and water erosion, litter movement, etc. become more apparent.

Indicator	Plus	Intermediate	Minus
10. Cover-Distribution	Well distributed with bare ground areas small	Bare ground areas larger, more numerous and less uniform in distribution	Bare ground areas numerous over large areas, most cover is under trees or shrubs, if present



Cover is well distributed with no larger bare areas (Plus).



Cover is concentrated under the shrub overstory with large bare areas between shrubs (Minus).

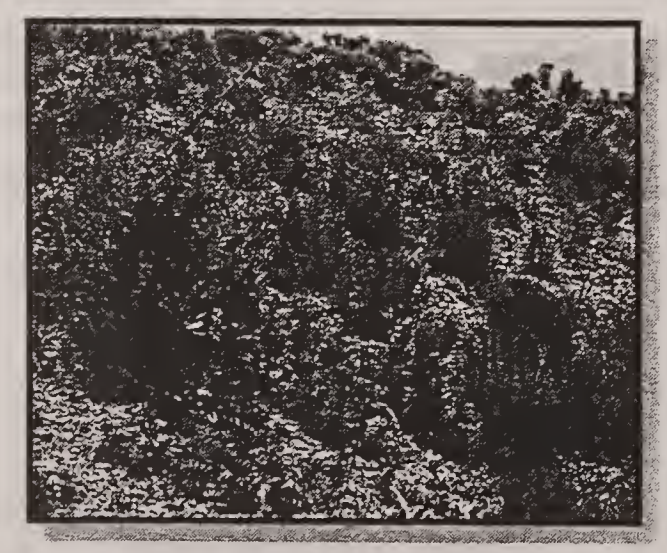
V. Interpreting Indicators of Biotic Integrity

In the biotic environment, indicators are used to assess the integrity, structure, and function of the flora and ecological processes. Most indicators of biotic integrity are focused on vegetation since they are the most easy to observe during the short period of time allocated to conducting the evaluation. Biotic indicators are listed in **Biotic Integrity Worksheet**. Both the **Species Abundance and Cover Worksheets** should be reviewed prior to completing the **Biotic Environment Worksheet (Appendix 1)**.

1. Community Diversity

Species specific assessments of plant diversity are not utilized in this process due to time, identification and phenology constraints. However the number of species by life form and representation of life form diversity relative to the site potential provides useful information on the general function and dynamics of the plant community relative to the site potential. Deterioration is indicated when the number of life forms and/or number of species by life form declines relative to site potential. An example of extreme deterioration of this indicator is the invasion and eventual dominance of exotic annual grasses e.g. cheatgrass, medusahead wildrye, red brome, etc. after repeated disturbance.

Indicator	Plus	Intermediate	Minus
1. Community Diversity	Good representation of life forms and #'s of species	One or two life forms poorly represented, #'s of species 70% of expected (ERAs)	Life forms dominated by one class, #'s of species < 50% of expected (ERAs)



Good life form and species diversity relative to the site potential (Plus).

Perennial grass and forb component missing relative to site potential (Minus).

2. Community Structure

Plant community structure is assessed by comparing life form heights and distribution on the site being evaluated with the site potential. Structural plant differences within life form classes should be considered in the evaluation. For example, tall bunchgrasses (basin wildrye), mid-height bunchgrasses (bluebunch wheatgrass) and short grasses (Sandberg bluegrass) may all be part of the site potential thus their relative abundance on the site under evaluation must be considered. An example of extreme deviation from the site potential is the invasion and eventual dominance of pinyon pine or juniper on a site with the potential for a mixture of grasses, forbs and shrubs but no trees.

The vertical root distribution of the species/life forms is also evaluated as a component of this indicator. The distribution of deep versus shallow rooted plants relative to the site potential is considered along with life form structure to rate this indicator. Vertical root distribution is an indicator of how well the vegetation on a site utilizes water and nutrients throughout the soil profile.

Indicator	Plus	Intermediate	Minus
2. Community Structure	Good diversity of height, size and distribution of plants including roots (vertical distribution)	Marginal diversity of height, size and distribution of plants and their roots	Plant community dominated by 1-2 life forms with poor height, size and distribution of species and their root systems

Dominant life forms and structural components (Joshua tree and blackbrush) are present relative to site potential (Plus).

Joshua trees and blackbrush are missing after wildfire and increase in exotics. Site structure is now dominated by annual and short lived perennial grasses and native half-shrub (Minus).

3. Exotic or Invasive Plants

The presence of exotic (non-native) or invasive (natives that are not part of the site potential) may slightly affect ecological processes if the infestation is small or the exotic plants function similarity to natives. Exotics/invasives may dominate sites by increased water usage such as salt cedar (tamarisk) or rapid nutrient depletion (e.g. nitrogen use by cheatgrass). This indicator ranges in values from little evidence or potential for expansion of exotics/invasives to dominance by these plants. Care must be exercised in evaluating invasive plants to insure that they are not a natural component of a site or that they greatly exceed the threshold of occurrence as described in the ecological site description or historical accounts.

Indicator	Plus	Intermediate	Minus
3. Noxious & Invasive Plants	Absent or sparse, pose little threat of expansion	Present along roads or scattered in plant community, pose threat of further expansion	Common in plant community with areas of exotic plant dominance

Single noxious weed plant (rush skeltonweed in a good stand of native grasses (Plus).

Rush skeletonweed expanding from road into adjacent degraded rangeland (Intermediate).

Former sagebrush steppe landscape converted to a cheatgrass monoculture after repeated wildfires (Minus).

4. Productivity

Above ground biomass production is an indicator of the efficiency of energy flow relative to the current climatic conditions and the site potential. The comparison of biomass production at the site potentia with evaluation sites can be made by estimating production at the ecological reference area or using the production ranges found in the ecological site description. It is critical that any comparison of biomass production be made on the same ecological site.

The amount of biomass removed due to herbivore utilization is not considered in the comparison, rather it is "mentally recreated" prior to making the comparison. This indicator is **not** intended to "measure" utilization rather it is a indicator of primary production on the same ecological site relative to site potential and climatic conditions.

Indicator	Plus	Intermediate	Minus
4. Productivity	Biomass production (all species, native and exotic) within 75% of expected production in relation to climate	Biomass production (all species, native and exotic) 50-75% of expected production in relation to climate	Biomass production (all species, native and exotic) less than 50% of expected production in relation to climate

Productivity of this site is near its potential relative to ecological site description and climate (Plus).

The productivity of this site has been reduced as a result of a wildfire, accelerated erosion and invasion of annual grasses (Minus).

5. Photosynthesis Activity

The energy flow can be evaluated by observing the amount and distribution of photosynthetic activity occurring on a site relative to the site potential. The proportion of warm to cool season plants may be changed by management negatively affecting the efficiency of use of solar energy, nutrients and water. For example, if plant community composition is changed from a cool season plant dominance to warm season plants the distribution of photosynthesis activity and therefore energy flow and nutrient cycling is modified. The ratio of deciduous and evergreen shrubs are another plant grouping that may affect the distribution of photosynthetic activity.

Cheatgrass, an exotic annual grass, has a shorter period of photosynthesis activity than the perennial shrubs and native herbs that it replaces after a disturbance. Total energy available for herbivores may be high on cheatgrass dominated rangelands during a 2-3 month period in the spring, however it decreases significantly after the cheatgrass matures in June. Native perennial plants, especially big sagebrush are active photosynthetically over most of the growing season.

A comparison of the composition of plants with different photosynthetic pathways may be made by including warm/cool season life forms on the Cover Worksheet or by comparing actual cool/warm season composition in the field with the ecological site description. Regional modification of the Cover Worksheet may be necessary to include categories of warm and cool season grasses, desert succulents etc.

Indicator	Plus	Intermediate	Minus
5. Photosynthesis Activity	Length and distribution similar to ecological reference area	Length and distribution is marginal compared to ecological reference area	Length and distribution dissimilar to ecological reference area

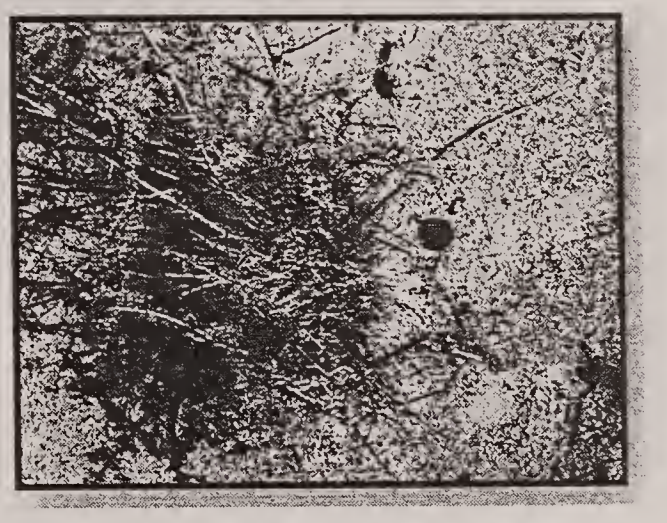
The length of the photosynthesis period is considerably less in the cheatgrass plant (right) than for the native greens grass (left).

6. Plant Status

The health of the plants in a community (e.g. vigor) are an indicator of the potential for reproduction and the maintenance of the integrity of the plant community. Productive plants relative to climatic conditions are one indicator of favorable plant status. Another component of this indicator is the presence of dead or decadent plants relative to the site potential. Plants stressed from excessive use may be more susceptible to disease or insect damage and more susceptible to mortality.

Indicator	Plus	Intermediate	Minus
6. Plant Status	Majority of plants are productive and alive	Signs of mortality in important species, production of remaining plants declining	Dead or decadent plants readily evident, production of remaining plants is poor.

All native life forms are alive and productive (Plus).

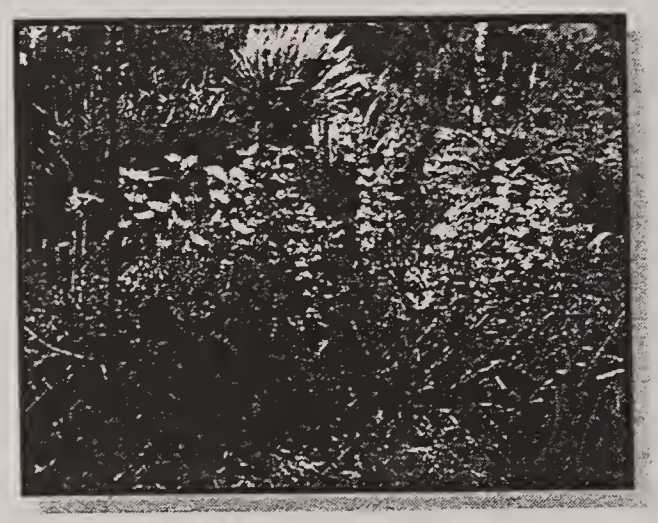


Native grass is protected by shrub crown and is in poor condition as evidenced by dead center, poor seed and biomass production (Intermediate).

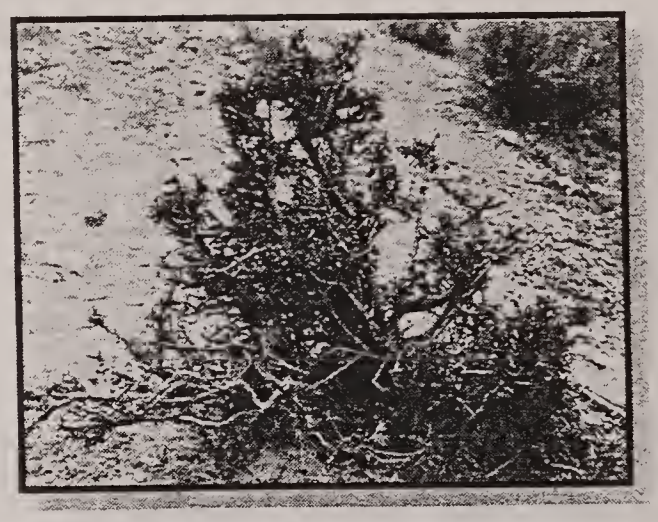
7. Seed Production

Adequate seed production of plants that reproduce sexually is essential to insure that reproduction of desired plants occurs when climatic events are favorable. Seed production can be assessed by comparing seedstalk and/or number of seeds per seedstalk or plant on the evaluation area with the production on the associated ecological reference area. Seed production is related to plant status since healthy plants are better able to produce abundant quantities of **viable** seed than are plants that are stressed or decadent.

Indicator	Plus	Intermediate	Minus
7. Seed Production (natives or seeded species)	Numbers of seedstalks/seed adequate for stand maintenance of all life forms	Plants stressed resulting in reduced seedstalk and seed production of some life forms	Seed/seedstalks inadequate for stand replacement during favorable recruitment periods



Native grasses and forbs with good seed production (Plus).

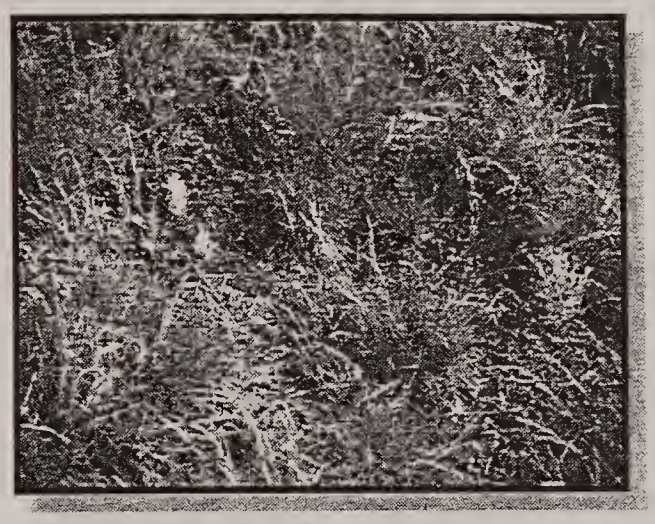


Severely hedged native shrub with no seed production and poor vigor (Minus).

8. Recruitment

Recruitment is an episodic event in many of the arid and semi-arid ecological sites in the West. Therefore evidence of recruitment (seedlings or vegetative spread) of perennial, desirable plants will not occur each year. Recruitment should be documented on the Ecological Reference Area and compared to recruitment on evaluation sites on the same ecological site. Using this approach the climatic and management effects on recruitment may be separated enhancing the value of the comparison.. Other physical site characteristics (surface crusting, litter, plant density, microbiotic crust, etc.) may also affect recruitment and should be observed on the ecological reference area and compared to the sites that are being evaluated. Time frames of expected recruitment episodes may be inserted into the Recruitment descriptors in the Biotic Environment Worksheet.

Indicator	Plus	Intermediate	Minus
8. Recruitment	Evidence of recruitment (seed- lings, juveniles or vegetative spread) in last 10 years	Recruitment in last 10 years is spotty and not fully representative of each life form	Minimal evidence of recruitment in last 10 years; some life forms have a high % of dead or decadent plants



Big sagebrush seedlings established in native grass community (Plus).

Sagebrush recruitment is occurring however recruitment of herbaceous species is not occurring in the bare interspaces (Intermediate).

9. Nutrient Cycle

The nutrient cycle is very complex and not easily assessed. Indicators of a functional status for the nutrient cycle include leguminous plants that fix nitrogen, litter that is available for decomposition into organic matter and presence of those components of the microbiotic crust that fix nitrogen. All of these indicators are compared to the ecological reference area(s) or site description as part of the evaluation process. Leguminous plants that fix nitrogen should be identified in the office prior to field evaluations to insure proper recognition during field work.

Decomposed litter and plant roots are important sources of organic matter, including nitrogen in all but the driest deserts. Litter can not accumulate and be available for decomposition if plant growth is heavily utilized by herbivores throughout the growing season. In arid environments litter may oxidize in the sun as evidenced by a gray cast to the litter. This litter is not available for decomposition, therefore root decomposition is probably a more important source of organic matter.

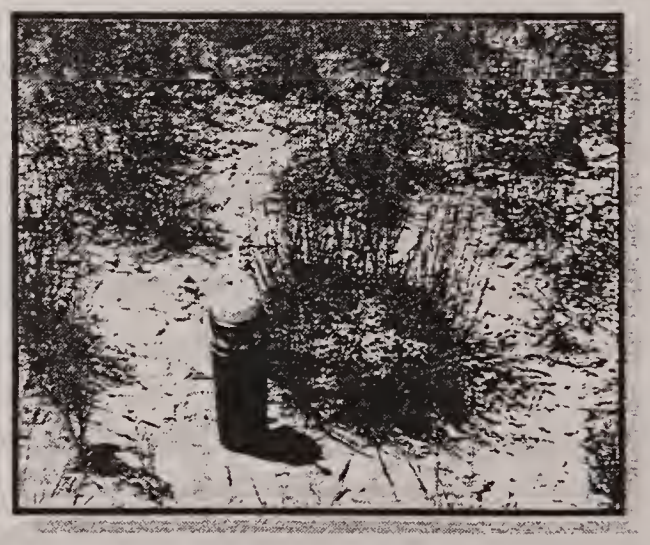
Microbiotic crusts are composed of mosses, lichens, algae, microfungi, cyanobacteria and bacteria growing on or just below the soil surface. Some lichens and cyanobacteria fix nitrogen and thus are important in nutrient cycling. However, caution in interpreting the role of microbiotic crust in nutrient cycling is urged as little is know about this function in many western ecosystems.

Indicator	Plus	Intermediate	Minus
9. Nutrient Cycle	Mechanisms (leguminous plants, cryptogamic crust, litter, etc) are adequate for plant maintenance)	Mechanisms are marginally adequate for plant maintenance and life form representation	Mechanisms are inadequate to maintain plant community life forms

Nitrogen fixing plants, like this *Astragalus spp.* may be important sources of Nitrogen (Plus).

Nitrogen is fixed by cyanobacteria and some lichens (e.g. microbiotic crust) in arid environments (Plus).

The decomposition of organic matter, especially litter, is an important source of nutrients (Plus).



Lack of litter and microbiotic crust indicates a poorly functioning nutrient cycle in this crested wheatgrass seeding (Minus).

VI. Seedings of Introduced Plants

Seedings represent a special situation since the original plant community and microbiotic crust have been disrupted by a seedbed preparation treatment (burning, plowing, herbicide application, etc.) and the perennial plant community replaced by seeding either native or non-native (more common) plants. The use of non-native plants in a seeding does not preclude ecological processes from functioning properly or adversely affect biotic integrity if:

1. The non-native plants fulfil similar ecological and structural roles in the new plant community. For example crested wheatgrass fulfils **some** of the same structural and ecological roles that the native bluebunch wheatgrass does. They are both cool season bunchgrasses that have similar phenology and production curves.

2. The non-natives are not planted in monocultures or in seed mixtures that lack the life forms that were in the site potential. For example, planting a mixture of crested wheatgrass and dryland alfalfa rarely results in a "healthy" plant community for the first 10-30 years since species diversity is low and the "keystone" shrub, big sagebrush, returns to this type of seeding slowly unless it is heavily grazed and has nearby seed sources.

Indicators of rangeland health should be evaluated the same on seedings as they are on a native plant community keeping in mind the time since the seeding was established. It is not likely that sagebrush will return to pre-fire levels on proper functioning rangeland in less than ten years, therefore it is not reasonable that a seeding of non-natives is judged improperly functioning just because it does not have abundant big sagebrush plants in a short period of time after seeding.

Crested wheatgrass and sagebrush were planted at low rates allowing native plants to recover (Plus).

Ecological processes do no function properly in monoculture planting of crested wheatgrass (Minus).

VII. Determining the Functional Status of the Physical Environment and Biotic Integrity Indicators.

The critical link between observations of indicators and determining the functional status of the health of a landscape unit is the interpretation process. The indicators are evaluated and a determination of physical site stability and biotic integrity are made. This procedure relies upon the collective experience and knowledge of the interdisciplinary team to classify each indicator and then to interpret the collective rating for the indicators into one summary rating. This summary rating is made by reviewing the indicator ratings, comments and the Cover and Species Abundance Worksheets. The interdisciplinary team then selects the appropriate summary rating on the back of each worksheet (Appendix 1) based upon a "preponderance of evidence" approach. The category (plus, intermediate, minus) where the majority of the indicators are centered around is selected to represent the functional status of the either the Physical Environment or Biotic Integrity.

The product of each of the worksheets is a single rating of the physical site stability or biotic integrity selected based on the categories of:

Functioning- majority of indicators are in the "plus" category indicating that the physical site stability or biotic integrity is acceptable relative to the ecological reference area, climate and disturbance regime.

Poorly Functioning (at risk)- indicators are "centered" around the intermediate category with some indicators possibly in the "plus" and "minus" categories.

Marginally Functioning- this category is divided into two sub-categories, one of which is selected to characterize the site.

A.) Marginally Functioning, Responsive to Management- majority of indicators in the "minus" category although there is potential to improve the rating of this site to ***Functioning at Risk*** or ***Functioning*** with the application of non-intensive management. Non-intensive management is the application in changes in grazing management (season of use, time of use, class of livestock, intensity of use, etc.) or the use of a natural process (e.g. prescribed fire).

B.) Marginally Functioning, Unresponsive to Management- majority of indicators in the "minus" category with minimal potential to improve the rating of this site to ***Functioning at Risk*** or ***Functioning*** with the application of non-intensive management. The only potential to improve this site is the application of rehabilitation or restoration practices including, but not limited to, weed control (herbicide, plowing, burning, introduction of biological control agents or combinations of treatments) and reseeding desired vegetation.

Selection of the appropriate rating within the *Marginally Functioning* category requires the interdisciplinary team to have practical experience in applying intensive and non-intensive management practices. If this expertise is unavailable during the field evaluation, later consultations with experienced practioners may aid in making the determination.

Remember these two ratings are only an indication of ecological problems and should not be construed to **solely** represent the health status of the site. The rating may indicate the need for additional studies or further analysis and interpretation of existing monitoring and inventory data. Grazing changes should not be made solely on the findings from this process.

VIII. Modifying Indicators and Descriptors

The indicators included in these worksheets are not intended to be all inclusive for all western rangelands. It is not expected that many of the indicators would be eliminated given the extensive field testing; however additional indicators may be added to the worksheets to improve the sensitivity of worksheets in detecting changes in physical site stability and biotic integrity.

In some cases it will be necessary to change the descriptor wording for some indicators in order to better reflect the potential of certain ecological sites. This may be required where physical site stability indicators are not accurate in reflecting the actual erosion expected on highly erosive sites. The wording of the existing descriptors generally reflects less erosive ecological sites. An example of descriptor changes to better represent a **naturally** highly erosive ecological reference area follows.

Existing Indicator/Descriptors

Indicator	Plus	Intermediate	Minus
3. Soil Movement-Water	None to slight	Moderate, slight terracing & some short pedastals	Significant movement with each event, rocks and plants on pedastals, some roots exposed

Modified Indicator/Descriptors for Naturally Erosive Site

Indicator	Plus	Intermediate	Minus
3. Soil Movement-Water	Moderate, slight terracing & some short pedastals. Few rills and no gullies	Moderate to high, terraces and pedastals widely evident, rills numerous with few gullies.	Excessive movement with each event. most plants pedastalled with exposed roots. Rills at frequent intervals and >3" deep. Gullies numerous & active

Changes in indicators and descriptor wording should be done by an experienced team of interdisciplinary specialists, including a soil scientist (contact local NRCS office if agency soil scientist is not available) after a thorough ecological reference area(s) and ecological site description review.

Example of a naturally erosive ecological site where descriptor modification is necessary

XIV. Applications

There are several applications of the interpretation of indicators of rangeland health. It should be remembered that the use of the four worksheets described above are not intended to be used alone for the following applications. Existing monitoring and inventory data along with the knowledge of the interdisciplinary team are all important in the evaluation of rangeland health.

A. Communication Tool

The primary value of this process is as a communication tool between BLM personnel and the publics interested in management of BLM administered lands for "rangeland health". The BLM is required by regulations (43 CFR Subpart 4180) to manage public rangelands to meet or make significant progress towards meeting "Standards for Rangeland Health". The interpretation of appropriate indicators of rangeland health can be used to supplement existing monitoring and inventory data to make this determination.

B. Indicator Evaluation

This process can also be used provide resource managers and the public with a tool to evaluate the functional status of the Physical Environment and Biotic Integrity in a relatively short period of time. When used as an evaluation tool it is important to remember that:

This procedure does not establish the cause of improperly functioning of ecological processes, it simply identifies where a problem exists. This procedure is not intended nor designed to replace quantitative monitoring, serve as a trend indicator, or provide data that can be aggregated for a national report on rangeland health.

SUMMARY

The interpretation of indicators of rangeland health by a well founded and trained interdisciplinary

team can be a valuable tool for communication with the public and for evaluation purposes. These evaluations may provide land managers with timely information on site stability and biotic integrity. Early warnings of resource problems allow application of remedial management actions before site degradation proceeds to a nonfunctioning or unhealthy situation. However, more research is needed to quantify indicator attributes and identify thresholds for physical and biotic status. Once this information is available the assessment of rangeland health will become more of a "science" and less of an "art".

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Appendix 1. Rangeland Health Worksheets

Site Documentation Worksheet

State_____ **District/Region**_____

Management Unit (Allotment)_____ Watershed_____

Pasture_____ **Reference Area**: Yes____ or No____

Major Land Resource Area_____

Identification Number (if applicable)_____ **Photo(s) Taken**: Yes ____ or No____

Location: Legal T.___ ,R.___ , Sec.____ , ___1/4, ___ 1/4.

Latitude _____ , Longitude _____ or UTM Coordinates _____

Observers:_____**Date:**_____

SITE CHARACTERISTICS

Ecological Site_____

Soil Map Unit Name _____

Geology or Parent Material_____ Aspect_____

Slope _____ Elevation_____ft. Topographic position _____

Annual Precip. _____ **Recent climate**: 1)Drought___, 2) Normal____, or 3) Wet____

SITE USES

Describe wildlife and livestock use in the area of the assessment_____

_____

_____

Describe evidence of recent disturbance (wildfire, recreation, grasshoppers,etc._____

_____

_____

COMMENTS (write on back of this form)

Cover Worksheet

ESTIMATED LIFE FORMS AND GROUND COVER (%)								
COVER CLASSES	0	0-1	1-5	6-15	16-30	31-50	51-75	75-100
LIFE FORMS								
I - GRASS								
Annuals								
Native Perennial								
Exotic Perennial								
II - FORBS								
Annual								
Perennial								
III - SHRUBS								
IV - TREES								
V - SUCCULENTS								
VI- MICROBIOTIC CRUST								
GROUND COVER								
I- LITTER								
II- BARE GROUND								
III- ROCK/GRAVEL								
IV- MICROBIOTIC CRUST								
V- VASCULAR PLANTS								

All ground cover in Categories I.-IV. are estimated from **interspace** areas only. Category V. is an estimate of total vascular plant cover; overlapping canopies are counted as only one canopy.

COMMENTS-

Species Abundance Worksheet

The dominant species are ranked (1-3) according to abundance on the site (1-4, Section I) and by lifeform (1-3, Section II). Abundance is determined based upon cover. Noxious weeds are also identified by species(Section III).

Section I- Dominant Species on Site

1. _____

2. _____

3. _____

4. _____

Section II- Dominant species by lifeform

Annual Grasses.

1. _____

2. _____

3. _____

Annual Forbs.

1. _____

2. _____

3. _____

Perennial Grasses

1. _____

2. _____

3. _____

Perennial Forbs

1. _____

2. _____

3. _____

Shrubs and Trees

1. _____

2. _____

3. _____

Section III- Noxious weeds

1. _____

2. _____

3. _____

Comments _____

_____

Physical Environment Worksheet

Relative to Ecological Reference Area(s)-ERA

Indicator	Plus	Intermediate	Minus
1. Surface Litter	In place or slight movement	Moderate movement, bigger litter displaced	Extreme movement, occurs with each event
2. Soil Movement - Water	None to slight	Moderate, slight terracing & some short pedastals	Significant movement with each event, rocks and plants on pedastals, some roots exposed
3. Flow Patterns	Few, slight deposition	Well defined, small with intermittent deposits	Numerous with soil deposit
4. Soil Movement-Wind	None to slight	Wind scoured depressions evident, small aeolian deposits around plant clumps	Wind scoured depressions common with large aeolian deposits around plant clumps
5. Soil Crusting & Surface Sealing	None to minimal with "soft" physical and/or chemical crusts	Physical and/or chemical crusting obvious with reduced infiltration occurring	Hard physical and chemical crusts widespread on bare ground, strongly reducing infiltration
6. Compaction Layer	None to minimal, not restrictive	Thin, weakly restrictive to roots and water	Extensive with > 1" width, strongly restrictive
7. Rills	If present, rare and widely spaced	Occasionally present, < 3" deep	Very common at 5' or less intervals, up to 6" deep
8. Gullies	None to few, if present gullies are healing (veg. on sides & bottom)	Few present, active erosion (incised sides) on <10% of length	Numerous with active erosion on 20% or more of length, some headcutting evident
9. Cover- Amount	Adequate (>X %) to protect site from accelerated erosion.	Marginal (around X %) for site protection, accelerated erosion starting	Inadequate (<X %) for site protection, accelerated erosion evident
10. Cover-Distribution	Well distributed with bare ground areas small	Bare ground areas larger, more numerous and less uniform in distribution	Bare ground areas numerous over large areas, most cover is under trees or shrubs, if present

Ecol. Ref. Area---->

Evaluation Area(s)-->

Physical Environment Summary Rating

Check One

1. **Functioning**___ 2. **Poorly Functioning**___ (at risk) 3. **Marginally Functioning**: ___ &

Check one:

a) Responsive to Management ___

b) Unresponsive to Mgt. ___

Rationale:

Comments on Indicators

1. Surface Litter

2. Soil Movement- Water

3. Flow Patterns

4. Soil Movement- Wind

5. Soil Crusting & Surface Sealing

6. Compaction Layer

7. Rills

8. Gullies

9. Cover- Amount

10. Cover- Distribution

Other Comments

Biotic Integrity Worksheet
Relative to Ecological Reference Area(s)-ERA

Indicator	Plus	Intermdiate	Minus
1. Community Diversity	Good representation of lifeforms and #'s of species	One or two lifeforms poorly represented, #'s of species 70% of expected	Lifeforms dominated by one class, #'s of species < 50% of expected (ERAs)
2. Community Structure	Good diversity of height, size and distribution of plants including roots (vertical distribution)	Marginal diversity of height, size and distribution of plants and their roots	Plant community dominated by 1-2 lifeforms with poor height, size and distribution of species and their root systems
3. Noxious & Invasive Plants	Absent or sparse, pose little threat of expansion	Present along roads or scattered in plant community, pose threat of further expansion	Common in plant community with areas of dominance
4. Productivity	Biomass production (total native and exotic) within 75% of expected prod. relative to climate	Biomass production (total native and exotic) between 50-75% of expected prod. relative to climate	Biomass production (total native and exotic) less than 50% of expected prod. relative to climate
5. Photosynthesis Activity	Length and distribution similar to ecological reference area	Length and distribution is marginal compared to ecological reference area	Length and distribution dissimilar to ecological reference area
6. Plant Status	Majority of plants (native) are productive and alive	Signs of mortality in key native species, production of remaining plants declining	Dead or decadent plants readily evident, production of remaining native plants is poor.
7. Seed Production	Numbers of seedstalks or seed adequate for stand maintenance of all native or seeded lifeforms	Native or seeded plants stressed resulting in reduced seedstalk and seed production of some lifeforms	Inadequate seed/seedstalks for stand replacement of all native or seeded lifeforms during favorable recruitment periods
8. Recruitment	Evidence of recruitment (seedlings, juveniles or vegetative spread) during last recruitment pulse	Recruitment is spotty and not fully representative of each lifeform relative to last favorable recruitment period	Minimal evidence of recruitment in last favorable recruitment period years; some lifeforms have a high % of dead or decadent plants
9. Nutrient Cycle	Mechanisms(leguminous plants, cryptogamic crust, litter, etc) are adequate for plant maintenance)	Mechanisms are marginally adequate for plant maintenance and lifeform representation	Mechanisms are inadequate to maintain plant favorable recruitment period community lifeforms

Ecol Ref Area->

Evaluation Area

Biotic Integrity Summary Rating

Check One

1. **Functioning**___ 2. **Poorly Functioning**___ (at risk) 3. **Marginally Functioning**: ___

Check one:

a) Responsive to Management ___

b) Unresponsive to Management ___

Rationale:

Comments on Indicators

1. Community Diversity

2. Community Structure & Root Distribution

3. Exotic Plants

4. Productivity

5 Photosynthesis Period

6. Plant Status

7. Seed Production

8. Recruitment

9. Nutrient Cycle

Appendix 2. Example of Completed Worksheets

The ecological reference area selected by the Interdisciplinary Team is shown in the first photograph and the area to be evaluated is shown in the second photograph. The ecological site description and existing monitoring and inventory studies were evaluated prior to and during the field evaluation of rangeland health.

Ecological Reference Area for Loamy 10-12" PZ (Wyoming big sagebrush/Bluebunch Wheatgrass Ecological Site **(R).**

Area evaluated by Interdisciplinary Team on same ecological site as Ecological Reference Area. Understory is dominated by cheatgrass with little perennial grasses or microbiotic crust remaining (**X**).

Site Documentation Worksheet

State Idaho **District/Region** Lower Snake

Management Unit (Allotment) Castle Watershed Beerch

Pasture Lower Spring **Reference Area**: Yes √ or No √

Major Land Resource Area _____

Identification Number (if applicable) _____ **Photo(s) Taken**: Yes √ or No ____

Location: Legal T. 12S ,R. 10E , Sec. 12 , NW 1/4, SE 1/4.

Latitude _____ , Longitude _____ or UTM Coordinates _____

Observers: J. Range, B. Wildlife, D. Soils, & P. Watershed **Date: 6/5/98**

SITE CHARACTERISTICS

Ecological Site Loamy 10-12" Precip. Zone (Artr-w/Agsp)

Soil Map Unit Name Tindahay Silt Loam

Geology or Parent Material Alluvium Aspect South

Slope 1-3% Elevation 3,200 ft. Topographic position Bench

Annual Precip. 11" **Recent climate**: 1)Drought ___, 2) Normal √, or 3) Wet ____

SITE USES

Describe wildlife and livestock use in the area of the assessment

Herbaceous species have been utilized at 10% level by cattle (still in area) and antelope.

Describe evidence of recent disturbance (wildfire, recreation, grasshoppers,etc.

No signs of disturbance other that previously described livestock and antelope

COMMENTS (write on back of this form)

Cover Worksheet

ESTIMATED LIFE FORMS AND GROUND COVER (%)								
COVER CLASSES	0	0-1	1-5	6-15	16-30	31-50	51-75	75-100
LIFE FORMS								
I - GRASS								
Annuals-Cheatgrass		R			X			
Native Perennial		X		R				
Exotic Perennial		R X						
II - FORBS								
Annual			R	X				
Perennial		X	R					
III - SHRUBS				R	X			
IV - TREES	R X							
V - SUCCULENTS		R	X					
VI- MICROBIOTIC CRUST			X		R			
GROUND COVER								
I- LITTER			R		X			
II- BARE GROUND		X	R					
III- ROCK/GRAVEL		XR						
IV- MICROBIOTIC CRUST		X			R			
V- VASCULAR PLANTS					R	X		

All ground cover in Categories I.-IV. are estimated from **interspace** areas only. Category V. is an estimate of total vascular plant cover; overlapping canopies are counted as only one canopy.

COMMENTS-

Species Abundance Worksheet

The dominant species are ranked (1-3) according to abundance on the site (1-4, Section I) and by life form (1-3, Section II). Abundance is determined based upon cover. Noxious weeds are also identified by species(Section III).

Section I- Dominant Species on Site

1.R- Bluebunch wheatgrass, X- Cheatgrass

2.R- Wyo. Big Sagebrush X-Wyo. Big Sagebrush

3.R- Bottlebrush Squirreltail, X-Mustard (exotic)

4.R- Sandberg bluegrass, X- Sandberg bluegrass

Section II- Dominant species by life form

Annual Grasses.

1.R-Six Weeks Fescue X- Cheatgrass

2._____

3._____

Annual Forbs.

1._X- Exotic Mustard

2._____

3._____

Perennial Grasses

1.R-Bluebunch wheatgrass X- Sandberg bluegrass

2R Bottlebrush squirreltail

3.R- Sandberg bluegrass

Perennial Forbs

1.R-Crepis spp X-Lupine

2.R-Astragalus spp.

3.R-Scarlet globemallow

Shrubs and Trees

1.R & X- Wyo. Big Sagebrush+

2.R-Spiny Hopsage

3._____

Section III- Noxious weeds

1. None observed

2._____

3._____

Succulents _____

Comments_____

Physical Environment Worksheet

Relative to Ecological Reference Area(s)-ERA

Indicator	Plus	Intermediate	Minus
1. Surface Litter	In place or slight movement	Moderate movement, bigger litter displaced	Extreme movement, occurs with each event
2. Soil Movement - Water	None to slight	Moderate, slight terracing & some short pedastals	Significant movement with each event, rocks and plants on pedastals, some roots exposed
3. Flow Patterns	Few, slight deposition	Well defined, small with intermittent deposits	Numerous with soil deposit
4. Soil Movement-Wind	None to slight	Wind scoured depressions evident, small aeolian deposits around plant clumps	Wind scoured depressions common with large aeolian deposits around plant clumps
5. Soil Crusting & Surface Sealing	None to minimal with "soft" physical and/or chemical crusts	Physical and/or chemical crusting obvious with reduced infiltration occurring	Hard physical and chemical crusts widespread on bare ground, strongly reducing infiltration
6. Compaction Layer	None to minimal, not restrictive	Thin, weakly restrictive to roots and water	Extensive with > 1" width, strongly restrictive
7. Rills	If present, rare and widely spaced	Occasionally present, < 3" deep	Very common at 5' or less intervals, up to 6" deep
8. Gullies	None to few, if present gullies are healing (veg. on sides & bottom)	Few present, active erosion (incised sides) on <10% of length	Numerous with active erosion on 20% or more of length, some headcutting evident
9. Cover- Amount	Adequate (>X %) to protect site from accelerated erosion.	Marginal (around X %) for site protection, accelerated erosion starting	Inadequate (<X %) for site protection, accelerated erosion evident
10. Cover-Distribution	Well distributed with bare ground areas small	Bare ground areas larger, more numerous and less uniform in distribution	Bare ground areas numerous over large areas, most cover is under trees or shrubs, if present

Ecol. Ref. Area---->	4--1-7 - 3-2-8--10----5---9-	-----6----------	----------
Evaluation Area(s)-->	7 5 9 8 1 10 4 2	6	

Physical Environment Summary Rating

Check One

1. **Functioning_R_X**
2. **Poorly Functioning___** (at risk)
3. **Marginally Functioning**: ___ &
   Check one:
   a) Responsive to Management ___
   b) Unresponsive to Mgt. ___

Rationale: Evaluation area (denoted with **X**) has a low percentage of bare ground due to high cheatgrass and litter cover. Signs of accelerated erosion in evaluation area are minimal.

Comments on Indicators

1. **Surface Litter**- Lots of litter on evaluation area due to cheatgrass

2. **Soil Movement**- Water

3. **Flow Patterns**

4. **Soil Movement**- Wind

5. **Soil Crusting & Surface Sealing**

6. **Compaction Layer**- Compaction layer was present on both ecological reference area and evaluation area although the effects were noticeable on infiltration or percolation of precipitation into soil.

7. **Rills**

8. **Gullies**- Several small gullies in evaluation area but there was no signs of current active erosion.

9. **Cover- Amount**

10. **Cover- Distribution**

Other Comments

Biotic Integrity Worksheet
Relative to Ecological Reference Area(s)-ERA

Indicator	Plus	Intermediate	Minus
1. Community Diversity	Good representation of life forms and #'s of species	One or two life forms poorly represented, #'s of species 70% of expected	Life forms dominated by one class, #'s of species < 50% of expected (ERAs)
2. Community Structure	Good diversity of height, size and distribution of plants including roots (vertical distribution)	Marginal diversity of height, size and distribution of plants and their roots	Plant community dominated by 1-2 life forms with poor height, size and distribution of species and their root systems
3. Noxious & Invasive Plants	Absent or sparse, pose little threat of expansion	Present along roads or scattered in plant community, pose threat of further expansion	Common in plant community with areas of dominance
4. Productivity 8.	Biomass production (total native and exotic) within 75% of expected prod. relative to climate	Biomass production (total native and exotic) between 50-75% of expected prod. relative to climate	Biomass production (total native and exotic) less than 50% of expected prod. relative to climate
5. Photosynthesis Activity	Length and distribution similar to ecological reference area	Length and distribution is marginal compared to ecological reference area	Length and distribution dissimilar to ecological reference area
6. Plant Status	Majority of plants (native) are productive and alive	Signs of mortality in key native species, production of remaining plants declining	Dead or decadent plants readily evident, production of remaining native plants is poor.
7. Seed Production	Numbers of seedstalks or seed adequate for stand maintenance of all native or seeded life forms	Native or seeded plants stressed resulting in reduced seedstalk and seed production of some life forms	Inadequate seed/seedstalks for stand replacement of all native or seeded life forms during favorable recruitment periods
8. Recruitment	Evidence of recruitment (seedlings, juveniles or vegetative spread) during last recruitment pulse	Recruitment is spotty and not fully representative of each life form relative to last favorable recruitment period	Minimal evidence of recruitment in last favorable recruitment period years; some life forms have a high % of dead or decadent plants
9. Nutrient Cycle	Mechanisms(leguminous plants, cryptogamic crust, litter, etc) are adequate for plant maintenance)	Mechanisms are marginally adequate for plant maintenance and life form representation	Mechanisms are inadequate to maintain plant favorable recruitment period community life forms

```
Ecol Ref Area->   --1--4--3--9--2-5---7--------|--6----------------8-----------------------|----------------------------------------
                                               |                                           |
Evaluation Area                        4       |6    2                  1    9   5 8 |   7                    3
```

Biotic Integrity Summary Rating

Check One

1. **Functioning_R_**
2. **Poorly Functioning_X** (at risk)
3. **Marginally Functioning**: ___
   Check one:
   a) Responsive to Management ___
   b) Unresponsive to Management ___

Rationale: The cheatgrass was the dominant plant in the understory of the evaluation area which adversely affected most of the indicators on the Biotic Worksheet.

Comments on Indicators

1. **Community Diversity**- Very few signs of native herbaceous (grass or forb) life forms in the evaluation area.

2. **Community Structure & Root Distribution**- The mid-height life forms (native grasses and forbs) were largely absent in evaluation area.

3. **Exotic Plants**- Cheatgrass dominates the understory in the evaluation area.

4. **Productivity**- Similar on ecological reference area and evaluation area even though cheatgrass was the doniminant plant on the evaluation area.

5 **Photosynthesis Period**- Similar between both sites although if the sagebrush was lost on the evaluation area the photosynthesis period would be considerably shorter thereafter.

6. **Plant Status**-.

7. **Seed Production**- Even though the precipitation was near normal for the current year, the seed production of remnant native herbaceous plants was very poor.

8. **Recruitment**- Some sagebrush recruitment in the evaluation area.

9. **Nutrient Cycle**- Decomposition of organic matter was marginally adequate in evaluation area for nutrient cycle.

APPENDIX J

RANGELAND HEALTH WORKSHEET					
ATTRIBUTE	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
RILLS	Rill formation is severe, well defined throughout most of the area at close intervals.	Rill formation is moderately active, well defined throughout most of the area at close intervals.	Active rill formation is slight at infrequent intervals, mostly in exposed areas.	No recent formation of rills; some evidence of past rill formation; old rills are blunted or muted.	Minimal evidence of recent or past formation of rills.
WATER FLOW PATTERNS	Flow patterns extensive and more numerous than expected; unstable with active erosion. Flow patterns connected.	Flow patterns more numerous than expected; deposition and cut areas common. Occasionally connected.	Flow patterns match what is expected for the site; erosion and deposition in flow pattern minor, but flow paths are not entirely stable.	Flow patterns match what is expected for the site. Little evidence of past erosion. Flow patterns are stable over the majority of the area.	Flow patterns are natural and stable and match what is expected for the site.
PEDESTALS CAUSED by WIND &/or WATER EROSION	Abundant active pedestaling. Most rocks and plants are affected; exposed plant roots are common.	Moderate active pedestaling. Some of rocks and plants are affected. Exposed plant roots are evident but not common.	Slight active pedestaling, most pedestals in flow paths, interspaces and/or on exposed slopes.	No indications of active pedestaling; some evidence of past pedestal formation, especially in flow paths and/or on exposed slopes.	Minimal current or past evidence of pedestalled plants or rocks.
BARE GROUND	Amount of bare ground much higher than expected for the site. Bare areas are large and are connected.	Amount of bare ground higher than expected for the site. Bare areas are large but are not connected.	Amount of bare ground slightly higher than expected for the site. Bare areas are moderate to small and clumped.	Amount of bare ground slightly higher than expected for the site. Size of bare areas are small.	Amount and distribution of bare areas matches that expected for the site.

RANGELAND HEALTH WORKSHEET (page two)

ATTRIBUTE	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
GULLIES	Present with active erosion, vegetation is intermittent on slopes and/or bed. Nickpoints are present and new headcuts occurring. Downcutting of channel is apparent.	Present with indications of active erosion, vegetation is intermittent on slopes and/or bed. Headcuts are active. Downcutting of channel not apparent.	Present with few indications of active erosion, vegetation is intermittent on slopes and/or bed. Some headcutting is evident.	Present but stable; vegetation is well established on bed and slopes; no visual signs of active cutting, nickpoints, or bed erosion.	Drainage areas represented as natural stable channels.
WIND EROSION	Smooth wind blown soil surfaces dominate the site. Soil loss is excessive.	Exposed plant roots, aeolian deposits around plants, lee side of depressions and ridges. Plants show evidence of wind damage.	Plants show evidence of wind damage, minimal exposed roots; aeolian deposits around obstructions and the lee side of depressions and ridges.	No evidence of active movement of soil; aeolian deposits on lee side of obstructions, depressions and ridges.	Minimal evidence of active or past movement of soil by wind; aeolian deposits not evident.
MICROBIOTIC CRUSTS	Microbiotic crusts found only in protected areas.	Microbiotic crusts largely absent, occurring mostly in protected areas.	Microbiotic crusts evident under shrubs or other protected sites with a minor component outside protected areas.	Microbiotic crusts evident throughout the site, but disturbed, broken and irregular in occurrence.	Microbiotic crusts are largely intact throughout site. Matches that expected for the site in amount and distribution.

APPENDIX J

RANGELAND HEALTH WORKSHEET (page three)					
ATTRIBUTE	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
SOIL SURFACE	Surface organic layer rarely present, and then only in association with prominent plants or other obstructions	25-50% of the surface organic layer is no longer present. Variations in depth of the soil surface between vegetation and interspaces exceeds 25%	Not more than 25% of the surface organic layer is present. Variations in the depth of the soil surface between vegetation and interspaces is less than 25%.	Some evidence of past loss of surface organic layer. The soil surface is presently stable and no evidence of current surface organic layer loss.	Minimal evidence of surface organic layer loss. Variations between vegetation and interspaces matches that expected for the site.
INFILTRATION CAPACITY AND RUNOFF	Infiltration capacity has been severely decreased and surface runoff has been severely increased by heavy compaction, physical crusting, and/or by adverse composition change in the plant community.	Infiltration capacity is moderately reduced and surface runoff is moderately increased by soil compaction, physical crusting and/or plant community composition changes.	Infiltration capacity and surface runoff have been moderately affected as evidenced by minor compaction layers or physical crusts. Plant community composition not negatively affecting infiltration or runoff.	Infiltration capacity and surface runoff have been temporarily affected. Little evidence of compaction or physical crusts.	Infiltration capacity and surface runoff are normal relative to that expected for the site.
PLANT MORTALITY	Plant mortality and/or decadence in excess of that expected for the site is common.	Dead plants and/or decadence in excess of that expected for the site is readily apparent.	Some dead plants and decadence above that expected for the site is apparent.	Slight evidence of plant mortality and decadence above that expected for the site.	Plant mortality and decadence matches that expected for the site.

RANGELAND HEALTH WORKSHEET (page four)

ATTRIBUTE	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
FUNCTIONAL PLANT GROUPS	Subdominant historical plant functional groups still dominate the site, but may be decreasing. Plant functional groups not present in the historic climax plant community are increasing and may become dominant.	Dominant historical plant functional groups no longer exist, a few individual species may persist. Subdominant historic plant functional groups dominate the site. Plant functional groups not present in the historic climax plant community may be increasing.	Dominant historic plant functional groups occur, but no longer dominate. Subdominant historic plant functional groups now dominate the site. Plant functional groups not present in the historic climax plant community may be appearing.	Dominant historic plant functional groups are decreasing, but still dominate. Subdominant historic plant functional groups are increasing.	Functional plant groups closely match that of the historic climax plant community.
LITTER DISTRIBUTION	Minimal woody and herbaceous litter accumulation evident.	Woody and herbaceous litter only in and under obstructions.	Litter distribution less than that expected for the site. Herbaceous litter concentrated in and around obstructions.	Litter distribution matches that expected for the site. Some herbaceous litter movement noticeable.	Litter distribution and movement by water or wind matches that expected for the site.
LITTER AMOUNT	Minimal litter accumulation evident.	Litter present, much less than expected for current conditions on the site.	Litter present, less than expected for the current conditions for the site.	Litter present, matches the current conditions for the site, but less or more than expected for the site.	Amount of litter is what is expected for the site.

RANGELAND HEALTH WORKSHEET (page five)					
ATTRIBUTE	CLASS I	CLASS II	CLASS III	CLASS IV	CLASS V
PLANT STRESS	Perennial vegetation is severely stressed.	Perennial vegetation is moderately stressed.	Perennial vegetation shows signs of short term stress.	Perennial vegetation showing few signs of short term stress.	Perennial vegetation showing minimal signs of any stress.
PRODUCTION	Productivity less than 20% of potential production.	Productivity 20-40% of potential production.	Productivity 40-60% of potential production.	Productivity 60-80% of potential production.	Productivity exceeds 80% of potential production.
INVASIVE PLANTS	Invasive plants dominate the site.	Invasive plants are common throughout the site.	Invasive plants are scattered throughout the site.	Invasive plants are present only in disturbed areas.	Invasive plants are not present on the site.
RECRUITMENT OR REPRODUCTION	Ability of plants to produce seed or vegetative tillers is severely reduced.	Ability of plants to produce seed or vegetative tillers is reduced.	Ability of plants to produce seed or vegetative tillers is somewhat limited.	Ability of plants to produce seed or vegetative tillers is only slightly affected.	Ability of plants to produce seed or vegetative tillers is not affected.

Hydrologic Characteristics-
Watershed Function

HYDROLOGIC CHARACTERISTICS - WATERSHED FUNCTION

A special module is planned for this section incorporating soil/site stability and hydrologic function. Topics include:

(1) Soil Quality/Health - Water regulation and partitioning function.

(2) Soil and Micro-Topographical relief characteristics and their influence on soil/water relationships.

(3) Soil Quality/Health influence on soil K factors.

Soil Properties and Associated Land Features

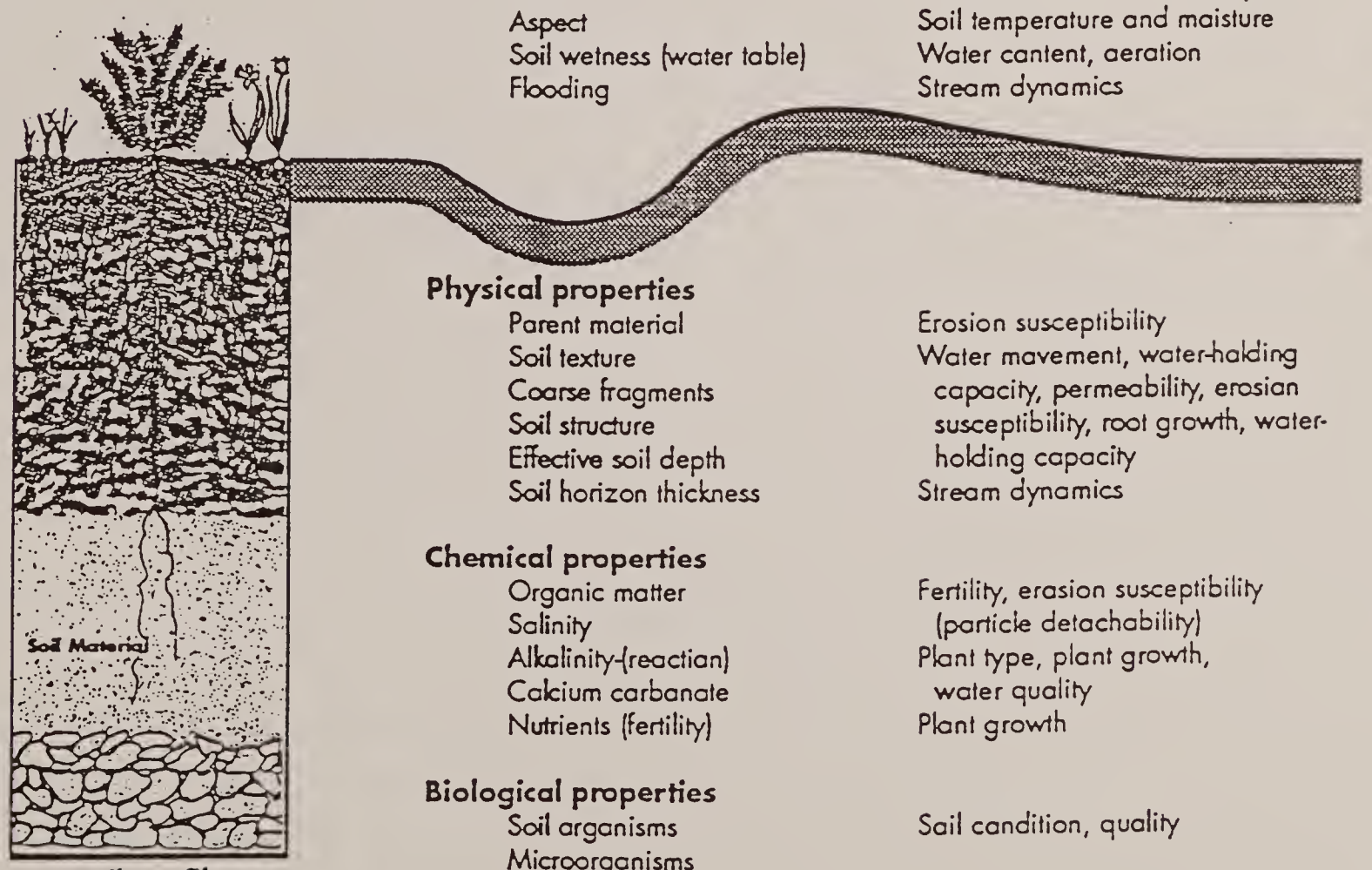
Soil data must identify the most important soil properties and associated land features that affect use and management for any selected use. In addition, one must know the limitation, if any, these parameters exert on the use in question. Such information is useful in determining what modifications and other management inputs are needed to develop the most efficient and effective use and management systems.

Keep in mind the importance of soil data (soil characteristics, properties, and associated land features) as they relate to soil quality, soil condition, soil vulnerability or fragility, and soil resilience.

Selected soil characteristics, properties, and associated land features that strongly affect soil-plant relations, soil erodability, and hydrologic condition

Soil Properties and Associated Land Features	Conditions Affected
Climate and Elevation	
Soil temperature regime	Plant type and growth
Soil moisture regime	Plant type and growth
Landform	
Slope	Soil marphalogy, drainage, soil-water relatians, erodability
Relief	
Aspect	Soil temperature and maisture
Soil wetness (water table)	Water cantent, aeration
Flooding	Stream dynamics
Physical properties	
Parent material	Erosion susceptibility
Soil texture	Water movement, water-halding capacity, permeability, erosian susceptibility, root growth, water-holding capacity
Coarse fragments	
Soil structure	
Effective soil depth	
Soil horizon thickness	Stream dynamics
Chemical properties	
Organic matter	Fertility, erasion susceptibility (particle detachability)
Salinity	
Alkalinity-(reactian)	Plant type, plant growth, water quality
Calcium carbanate	
Nutrients (fertility)	Plant growth
Biological properties	
Soil arganisms	Sail candition, quality
Microorganisms	

Setting and Associated Land Features



Soil Profile Properties

Interpretations/Management Actions

Local Soil/
Quality Information

Soil/Range Notes

Glossary

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grazing permit or lease and grazing preference, or a free use grazing permit or other grazing authorization, in whole or in part, under subpart 4160 of this title, for violation by a permittee or lessee of any of the provisions of this part.

(b) The authorized officer shall suspend the grazing use authorized under a grazing permit, in whole or in part, or shall cancel a grazing permit or lease and grazing preference, in whole or in part, under subpart 4160 of this title for repeated willful violation by a permittee or lessee of § 4140.1(b)(1) of this title.

(c) Whenever a nonpermittee or nonlessee violates § 4140.1(b) of this title and has not made satisfactory settlement under § 4150.3 of this title the authorized officer shall refer the matter to proper authorities for appropriate legal action by the United States against the violator.

(d) Any person found to have violated the provisions of § 4140.1(a)(6) after August 21, 1995, shall be required to pay twice the value of forage consumed as determined by the average monthly rate per AUM for pasturing livestock on privately owned land (excluding irrigated land) in each State as supplied annually by the National Agricultural Statistics Service, and all reasonable expenses incurred by the United States in detecting, investigating, and resolving violations. If the dollar equivalent value is not received by the authorized officer within 30 days of receipt of the final decision, the grazing permit or lease shall be cancelled. Such payment shall be in addition to any other penalties the authorized officer may impose under paragraph (a) of this section.

[46 FR 5792, Jan. 19, 1981, as amended at 50 FR 45827, Nov. 4, 1985; 60 FR 9969, Feb. 22, 1995]

§ 4170.1–2 Failure to use.

If a permittee or lessee has, for 2 consecutive grazing fee years, failed to make substantial use as authorized in the lease or permit, or has failed to maintain or use water base property in the grazing operation, the authorized officer, after consultation, coordination, and cooperation with the permittee or lessee and any lienholder of record, may cancel whatever amount of permitted use the permittee or lessee has failed to use.

[60 FR 9969, Feb. 22, 1995]

§ 4170.2 Penal provisions.

§ 4170.2–1 Penal provisions under the Taylor Grazing Act.

Under section 2 of the Act any person who willfully commits an act prohibited under § 4140.1(b), or who willfully violates approved special rules and regulations is punishable by a fine of not more than $500.

[60 FR 9969, Feb. 22, 1995]

§ 4170.2–2 Penal provisions under the Federal Land Policy and Management Act.

Under section 303(a) of the Federal Land Policy and Management Act of 1976 (43 U.S.C. 1701 *et seq.*), any person who knowingly and willfully commits an act prohibited under § 4140.1(b) or who knowingly and willfully violates approved special rules and regulations may be brought before a designated U.S. magistrate and is punishable by a fine in accordance with the applicable provisions of Title 18 of the United States Code, or imprisonment for not more than 12 months, or both.

[60 FR 9969, Feb. 22, 1995]

Subpart 4180—Fundamentals of Rangeland Health and Standards and Guidelines for Grazing Administration

§ 4180.1 Fundamentals of rangeland health.

The authorized officer shall take appropriate action under subparts 4110, 4120, 4130, and 4160 of this part as soon as practicable but not later than the start of the next grazing year upon determining that existing grazing management needs to be modified to ensure that the following conditions exist.

(a) Watersheds are in, or are making significant progress toward, properly functioning physical condition, including their upland, riparian-wetland, and aquatic components; soil and plant conditions support infiltration, soil moisture storage, and the release of water that are in balance with climate

and landform and maintain or improve water quality, water quantity, and timing and duration of flow.

(b) Ecological processes, including the hydrologic cycle, nutrient cycle, and energy flow, are maintained, or there is significant progress toward their attainment, in order to support healthy biotic populations and communities.

(c) Water quality complies with State water quality standards and achieves, or is making significant progress toward achieving, established BLM management objectives such as meeting wildlife needs.

(d) Habitats are, or are making significant progress toward being, restored or maintained for Federal threatened and endangered species, Federal Proposed, Category 1 and 2 Federal candidate and other special status species.

[60 FR 9969, Feb. 22, 1995]

§4180.2 Standards and guidelines for grazing administration.

(a) The Bureau of Land Management State Director, in consultation with the affected resource advisory councils where they exist, will identify the geographical area for which standards and guidelines are developed. Standards and guidelines will be developed for an entire state, or an area encompassing portions of more than 1 state, unless the Bureau of Land Management State Director, in consultation with the resource advisory councils, determines that the characteristics of an area are unique, and the rangelands within the area could not be adequately protected using standards and guidelines developed on a broader geographical scale.

(b) The Bureau of Land Management State Director, in consultation with affected Bureau of Land Management resource advisory councils, shall develop and amend State or regional standards and guidelines. The Bureau of Land Management State Director will also coordinate with Indian tribes, other State and Federal land management agencies responsible for the management of lands and resources within the region or area under consideration, and the public in the development of State or regional standards and guidelines. Standards and guidelines developed by the Bureau of Land Management State Director must provide for conformance with the fundamentals of §4180.1. State or regional standards or guidelines developed by the Bureau of Land Management State Director may not be implemented prior to their approval by the Secretary. Standards and guidelines made effective under paragraph (f) of this section may be modified by the Bureau of Land Management State Director, with approval of the Secretary, to address local ecosystems and management practices.

(c) The authorized officer shall take appropriate action as soon as practicable but not later than the start of the next grazing year upon determining that existing grazing management practices or levels of grazing use on public lands are significant factors in failing to achieve the standards and conform with the guidelines that are made effective under this section. Appropriate action means implementing actions pursuant to subparts 4110, 4120, 4130, and 4160 of this part that will result in significant progress toward fulfillment of the standards and significant progress toward conformance with the guidelines. Practices and activities subject to standards and guidelines include the development of grazing-related portions of activity plans, establishment of terms and conditions of permits, leases and other grazing authorizations, and range improvement activities such as vegetation manipulation, fence construction and development of water.

(d) At a minimum, State or regional standards developed under paragraphs (a) and (b) of this section must address the following:

(1) Watershed function;

(2) Nutrient cycling and energy flow;

(3) Water quality;

(4) Habitat for endangered, threatened, proposed, Candidate 1 or 2, or special status species; and

(5) Habitat quality for native plant and animal populations and communities.

(e) At a minimum, State or regional guidelines developed under paragraphs (a) and (b) of this section must address the following:

(1) Maintaining or promoting adequate amounts of vegetative ground

cover, including standing plant material and litter, to support infiltration, maintain soil moisture storage, and stabilize soils;

(2) Maintaining or promoting subsurface soil conditions that support permeability rates appropriate to climate and soils;

(3) Maintaining, improving or restoring riparian-wetland functions including energy dissipation, sediment capture, groundwater recharge, and stream bank stability;

(4) Maintaining or promoting stream channel morphology (e.g., gradient, width/depth ratio, channel roughness and sinuosity) and functions appropriate to climate and landform;

(5) Maintaining or promoting the appropriate kinds and amounts of soil organisms, plants and animals to support the hydrologic cycle, nutrient cycle, and energy flow;

(6) Promoting the opportunity for seedling establishment of appropriate plant species when climatic conditions and space allow;

(7) Maintaining, restoring or enhancing water quality to meet management objectives, such as meeting wildlife needs;

(8) Restoring, maintaining or enhancing habitats to assist in the recovery of Federal threatened and endangered species;

(9) Restoring, maintaining or enhancing habitats of Federal Proposed, Category 1 and 2 Federal candidate, and other special status species to promote their conservation;

(10) Maintaining or promoting the physical and biological conditions to sustain native populations and communities;

(11) Emphasizing native species in the support of ecological function; and

(12) Incorporating the use of non-native plant species only in those situations in which native species are not available in sufficient quantities or are incapable of maintaining or achieving properly functioning conditions and biological health;

(f) In the event that State or regional standards and guidelines are not completed and in effect by February 12, 1997, and until such time as State or regional standards and guidelines are developed and in effect, the following standards provided in paragraph (f)(1) of this section and guidelines provided in (f)(2) of this section shall apply and will be implemented in accordance with paragraph (c) of this section. However, the Secretary may grant, upon referral by the BLM of a formal recommendation by a resource advisory council, a postponement of the February 12, 1997, fallback standards and guidelines implementation date, not to exceed the 6-month period ending August 12, 1997. In determining whether to grant a postponement, the Secretary will consider, among other factors, long-term rangeland health and administrative efficiencies.

(1) *Fallback standards.* (i) Upland soils exhibit infiltration and permeability rates that are appropriate to soil type, climate and landform.

(ii) Riparian-wetland areas are in properly functioning condition.

(iii) Stream channel morphology (including but not limited to gradient, width/depth ratio, channel roughness and sinuosity) and functions are appropriate for the climate and landform.

(iv) Healthy, productive and diverse populations of native species exist and are maintained.

(2) *Fallback guidelines.* (i) Management practices maintain or promote adequate amounts of ground cover to support infiltration, maintain soil moisture storage, and stabilize soils;

(ii) Management practices maintain or promote soil conditions that support permeability rates that are appropriate to climate and soils;

(iii) Management practices maintain or promote sufficient residual vegetation to maintain, improve or restore riparian-wetland functions of energy dissipation, sediment capture, groundwater recharge and stream bank stability;

(iv) Management practices maintain or promote stream channel morphology (e.g., gradient, width/depth ratio, channel roughness and sinuosity) and functions that are appropriate to climate and landform;

(v) Management practices maintain or promote the appropriate kinds and amounts of soil organisms, plants and animals to support the hydrologic cycle, nutrient cycle, and energy flow;

(vi) Management practices maintain or promote the physical and biological conditions necessary to sustain native populations and communities;

(vii) Desired species are being allowed to complete seed dissemination in 1 out of every 3 years (Management actions will promote the opportunity for seedling establishment when climatic conditions and space allow.);

(viii) Conservation of Federal threatened or endangered, Proposed, Category 1 and 2 candidate, and other special status species is promoted by the restoration and maintenance of their habitats;

(ix) Native species are emphasized in the support of ecological function;

(x) Non-native plant species are used only in those situations in which native species are not readily available in sufficient quantities or are incapable of maintaining or achieving properly functioning conditions and biological health;

(xi) Periods of rest from disturbance or livestock use during times of critical plant growth or regrowth are provided when needed to achieve healthy, properly functioning conditions (The timing and duration of use periods shall be determined by the authorized officer.);

(xii) Continuous, season-long livestock use is allowed to occur only when it has been demonstrated to be consistent with achieving healthy, properly functioning ecosystems;

(xiii) Facilities are located away from riparian-wetland areas wherever they conflict with achieving or maintaining riparian-wetland function;

(xiv) The development of springs and seeps or other projects affecting water and associated resources shall be designed to protect the ecological functions and processes of those sites; and

(xv) Grazing on designated ephemeral (annual and perennial) rangeland is allowed to occur only if reliable estimates of production have been made, an identified level of annual growth or residue to remain on site at the end of the grazing season has been established, and adverse effects on perennial species are avoided.

[60 FR 9969, Feb. 22, 1995, as amended at 61 FR 59835, Nov. 25, 1996]

Group 4200—Grazing Administration; Alaska; Livestock

PART 4200—GRAZING ADMINISTRATION; ALASKA; LIVESTOCK

Subpart 4200—Grazing Administration; Alaska; Livestock; General

Subpart 4210—Conditions

Subpart 4220—Procedures

Subpart 4230—Disposition of Leased Lands

Subpart 4240—Protests, Hearings, and Appeals

AUTHORITY: Taylor Grazing Act of 1934, as amended (43 U.S.C. 315, 315(a)–315(r)), section 4 of the Act of August 28, 1937 (43 U.S.C. 1181(d)), and the Federal Land Policy and Management Act of 1976 (43 U.S.C. 1701 *et seq.*).

SOURCE: 43 FR 29062, July 5, 1978, unless otherwise noted.

Subpart 4200—Grazing Administration; Alaska; Livestock; General

§ 4200.0–2 Objectives.

The beneficial utilization of the public lands in Alaska for the purpose of livestock grazing shall be conducted in

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
WASHINGTON, D.C. 20240

April 10, 1998

In Reply Refer To:
4120, 4000 (240) P

EMS TRANSMISSION 4/10/98
Instruction Memorandum No. 98-91
Expires: 9/30/99

To: AFOs (excluding Alaska and Eastern States)

From: Assistant Director, Renewable Resources and Planning

Subject: Healthy Rangeland Initiative: Implementation of Standards and Guidelines

Standards and guidelines are to be used in several ways. The standards and guidelines and the information gained in assessing standards are an important communication tool. Addressing rangeland health in terms of the standards can aid in identifying the source of problems before they require corrective action and in identifying opportunities for management actions to best meet the standard. Additionally, they provide a clear statement and common understanding of the expected resource conditions and acceptable management practices. This common understanding will allow the livestock operator and BLM to design management practices and actions to achieve those standards consistent with the guidelines.

The standards and guidelines also define minimum resource conditions that must be achieved and maintained. As provided in the 1995 revisions to the grazing regulations, the BLM must ensure that grazing related actions conform with the appropriate standards and guidelines.

The purpose of this Instruction Memorandum is to--

- provide a brief overview of standards and guidelines implementation as described in the 1995 revisions to the grazing regulations and the 1994 Final Environmental Impact Statement,

- describe your responsibilities in the implementation of standards and guidelines as they pertain to the management of grazing of public lands, and

- introduce the DRAFT IMPLEMENTATION GUIDE.

Below is a series of questions and answers designed to accomplish the first two purposes listed above.

What is the purpose of the standards and guidelines?
The purpose of the standards and guidelines at 43 CFR subpart 4180 is to improve the health of the public rangelands. The standards and guidelines are intended to help the Bureau, rangeland users and others focus on a common understanding of acceptable resource conditions and work together to achieve that vision.

What is a standard?

Standards of rangeland health are expressions of levels of physical and biological condition or degree of function required for healthy, sustainable rangelands and define minimum resource conditions that must be achieved and maintained. Determination of rangeland health is based upon conformance with the standards. Application of the standard to the site considers the potential of the site without regard for the type or levels of use or management actions or decisions.

(Note: Standards may be supplemented with additional requirements where appropriate to meet resource objectives identified in an activity plan or land use plan. However, all resource objectives must, at a minimum, be consistent with the standards for the area.)

What is a guideline?

Guidelines for grazing management are types of grazing management methods and practices determined to be appropriate to ensure that standards can be met or that significant progress can be made toward meeting the standard. Guidelines are tools that help managers and permittees achieve standards. Guidelines implemented under 43 CFR 4180 are specific to livestock grazing. Guidelines are best management practices such as grazing systems, vegetative treatments, or improvement projects which could be used to achieve rangeland health standards.

How do I implement standards and guidelines?

An important aspect of standards and guidelines implementation requires that you ensure that all grazing related actions conform with the appropriate standards and guidelines. As described in the 1995 revisions to the grazing regulations, standards and guidelines implementation involves:

- prioritizing areas to be assessed,
- conducting assessments to determine if assessed areas meet, are making "significant progress" toward or fail to achieve standards or conform with guidelines,
- if failing, determining if grazing is a significant factor,

- if grazing is a significant factor, take appropriate action by modifying the terms and conditions, and
- evaluating the effectiveness of terms and conditions (See attached flow chart).

Standards and guidelines are to be implemented by applying terms and conditions to--

- grazing permits, leases and authorizations;
- grazing-related portions of activity plans (including Allotment Management Plans); and
- range improvement-related activities.

What is an assessment?

"Assessment" means the analysis, synthesis and interpretation of information, including monitoring data, to characterize the health of an allotment or other management unit. It is similar to "evaluation", as frequently used in the rangeland management program. Gathering new information in the field may be necessary as part of the assessment process.

How do I prioritize areas to assess?

You may choose an allotment or a group of allotments as a basis for an assessment or may use some other unit such as a watershed. The unit selected should have common resource characteristics at a scale appropriate to the complexity of the issues.

Prioritize areas by allotments, groups of allotments, watersheds or other areas and set a schedule for addressing them, giving priority to areas believed to be at risk--in degraded condition or downward trend and in danger of losing potential. This basic consideration may be supplemented with local criteria. You must document a clear rationale for selecting the assessment priority and determining the schedule to follow in conducting assessments and taking appropriate actions.

The process for prioritizing allotments or other areas must reflect the full range of physical and biological factors addressed by the standards. Previous allotment categorization (M, I, and C) may be useful in establishing priorities, but remember that the categorization process, in most cases, did not fully consider indicators of health and ecosystem function. You should strive to involve affected permittees and lessees, interested publics, other units of government and Indian tribes throughout the assessments, including activities associated with prioritizing allotments.

What is the goal of the assessment?

The goal of the assessment is to determine if areas are meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines.

What information is needed for an assessment?

Monitoring data collected in the past will often be an important source of information in conducting an assessment, but years of monitoring data are not necessarily required to complete an assessment. To determine whether current management is resulting in meeting the standards, you should use the best data and resource information available to you. This may include quantitative data from monitoring and inventories, qualitative information, professional knowledge, and knowledge provided by State agencies, public land users and others. Decisions must be made on a reasoned and rational basis, supportable, and well documented.

In limited cases, quantitative monitoring data, gathered over a period of years, may be essential in determining whether an area meets the standards or is making significant progress. It is anticipated that in these cases, it could take several grazing seasons to determine direction and magnitude of change. However, it would be inconsistent with our mandate to manage the public rangelands if we were to allow an allotment or watershed to deteriorate while prolonged monitoring studies are conducted. If reliable indicators of rangeland health demonstrate that areas are not meeting or not making significant progress toward meeting standards, you should take appropriate action.

If you determine that inadequate information is available to determine whether areas are meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines, you should, without delay, initiate action necessary to gather the minimum information needed to make the determination.

How long do I have to assess the rangelands under my jurisdiction?

You must complete the assessments in a reasonable time frame. In most states, Authorized Officers should ensure that at least ten percent of the livestock grazing lands under their jurisdiction are assessed each year until the assessments are complete. In states with an extremely large number of allotments, where assessing ten percent of the allotments per year would impose an impossible workload, a longer time-frame may be considered. In all states, the State Director should submit a draft implementation plan to the Assistant Director, WO-200 for approval, by August 1, 1998.

Is an assessment an action that can be protested and appealed under 43 CFR 4160?

No. Assessments are preliminary findings that build an administrative record. 43 CFR 4160 applies to actions (such as the renewal of a permit), terms and conditions, or modifications relating to applications, permits and agreements (including range improvement permits) or leases. As always, any applicant, permittee, lessee or any other person whose interest is adversely affected by a final decision of the authorized officer may appeal as provided in 43 CFR 4.470.

What if I determine an area or allotment is meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines?

If you determine an area or allotment meets the standards and conforms to the guidelines or is making significant progress toward meeting standards and conforming to guidelines, you must--

- review the existing terms and conditions to ensure that they will provide for continued achievement of (or progress towards meeting) the standards and guidelines, and

- continue monitoring and evaluation activities that will provide assurance that the area continues to meet the standards and conform to the guidelines or make significant progress toward meeting standards and conforming to guidelines.

What if I determine an area or allotment is not meeting standards and conforming to guidelines or not making significant progress toward meeting standards and conforming to guidelines?

If you determine an area or allotment fails to meet the standards and conform to the guidelines and is failing to make significant progress toward meeting standards and conforming to guidelines, you must determine if grazing is a significant factor.

What should I consider in determining if grazing is a significant factor in failing to achieve the standards and conform with the guidelines?

You should not assume that existing grazing management practices or levels of grazing use are significant factors in failing to achieve the standards and conform with the guidelines. You should determine if grazing is a factor only after reviewing the best resource information available to you. This may include quantitative data from monitoring and inventories, qualitative information, professional knowledge, and knowledge provided by public land users and others. Actions needed to improve grazing management to conform with guidelines or to meet standards should not be delayed solely because quantitative monitoring data are lacking.

If adequate information is not available to determine whether current livestock grazing is a significant factor in failing to meet the standards for a priority area, you should, without delay,

initiate action necessary to gather the minimum information needed to make the determination.

What do I do if grazing is not a significant factor in failing to achieve the standards and conform with the guidelines?

If you determine that existing grazing management practices or levels of grazing use are not significant factor(s) in failing to achieve the standards, you should consult other BLM guidance to revise management to meet the standards.

What do I do if grazing is a significant factor in failing to achieve the standards and conform with the guidelines?

If you determine that existing terms and conditions result in grazing management practices or levels of grazing use that are significant factor(s) in failing to achieve the standards and conform with the guidelines, you must modify the terms and conditions for grazing use.

By when must I modify the terms and conditions?

Upon your determination that existing grazing management practices or levels of grazing use are significant factor(s) in failing to achieve the standards and conform with the guidelines, you must modify the terms and conditions as soon as practicable but no later than the start of the next grazing year (March 1st).

What follows the modification of terms and conditions?

After modifying the terms and conditions, you should evaluate the effectiveness of the modified terms and conditions in meeting the standards and conforming to the guidelines. If future monitoring/evaluations indicate that the area has not achieved or is not making significant progress toward meeting the standards and conforming with the guidelines, again modify the terms and conditions as appropriate.

What are my responsibilities, once areas are meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines?

You have a responsibility to periodically monitor and evaluate areas to ensure they continue to meet the standards and conform to guidelines or to make significant progress toward meeting standards and conforming to guidelines.

While the assessment efforts are ongoing, what do I do when a permit or lease comes up for renewal or transfer for an unassessed allotment?

You should consider the renewal or transfer of a permit or lease to be an opportune time to

conduct an assessment of rangeland health and make any needed changes in the terms and conditions. If you do not conduct an assessment of rangeland health when a permit or lease is renewed or transferred, you must include terms and conditions that ensure achievement of the standards and conformance with appropriate guidelines. These terms and conditions must include a statement that if an assessment results in a determination that changes are necessary in order to comply with the standards and guidelines, the permit (or lease) will be reissued subject to revised terms and conditions.

The term of grazing permits or leases shall be for ten years, unless one of the exceptions listed in 43 CFR 4130.2(d) applies. Permits or leases may be revised if additional information indicates changes in management are needed to ensure allotments or areas are meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines.

How do standards and guidelines affect low priority allotments?

It may not be possible to complete assessments and take appropriate action within the near future for low priority allotments. Given workloads and priorities, it is conceivable that some allotments may never have terms and conditions specific to that allotment and that the general requirement to be in compliance with the standard is all that ever appears on the permit or lease. Regardless, in the event that grazing is determined to be a significant contributing factor in failing to achieve the standards or conform with the guidelines on a low priority allotment, you are required to take appropriate action under 43 CFR 4180.

How does standards and guidelines implementation affect our NEPA responsibilities?

The NEPA analysis for most State or regional standards and guidelines has been completed. However, as has long been the case, you must ensure NEPA compliance as terms and conditions are modified to ensure the terms and conditions result in meeting the standards and conforming to the guidelines or making significant progress toward meeting the standards and conforming to the guidelines.

How will we keep track of our efforts?

You must submit, by State, a progress report by October 15th of each year. You will be required to report by allotments and acreage the status of your implementation efforts. The format is provided in the attached DRAFT IMPLEMENTATION GUIDE, STANDARDS AND GUIDELINES FOR HEALTHY RANGELANDS

Summary

You need to move promptly to implement standards and guidelines and to take needed actions to improve rangeland health. 43 CFR subpart 4180 was written to achieve positive, on-the-ground changes in resource conditions. Development and approval of standards has been a significant accomplishment, but without full and effective implementation, it will be meaningless. Our goal as managers of the public rangelands must be to improve rangeland health and provide for multiple use and sustained yield of these lands. Implementation of the standards and guidelines is a critical means to reach that goal.

The overall purpose of the standards and guidelines is, in working with permittees, lessees and the public to make a difference on the land. Success will be measured in terms of concrete outcomes--not in terms of procedural actions. Success will be registered in recovering riparian areas, improved habitat conditions for wildlife, cleaner water, stabilized soils, robust native vegetation populations and sustainable livestock grazing operations. Procedural actions--plans written, data gathered, projects initiated, protests resolved or status reports filed--are merely means to an end. They are not, in and of themselves, the things about which our public *cares*. And they are not, in themselves, evidence of success. Our job is to change things on the land.

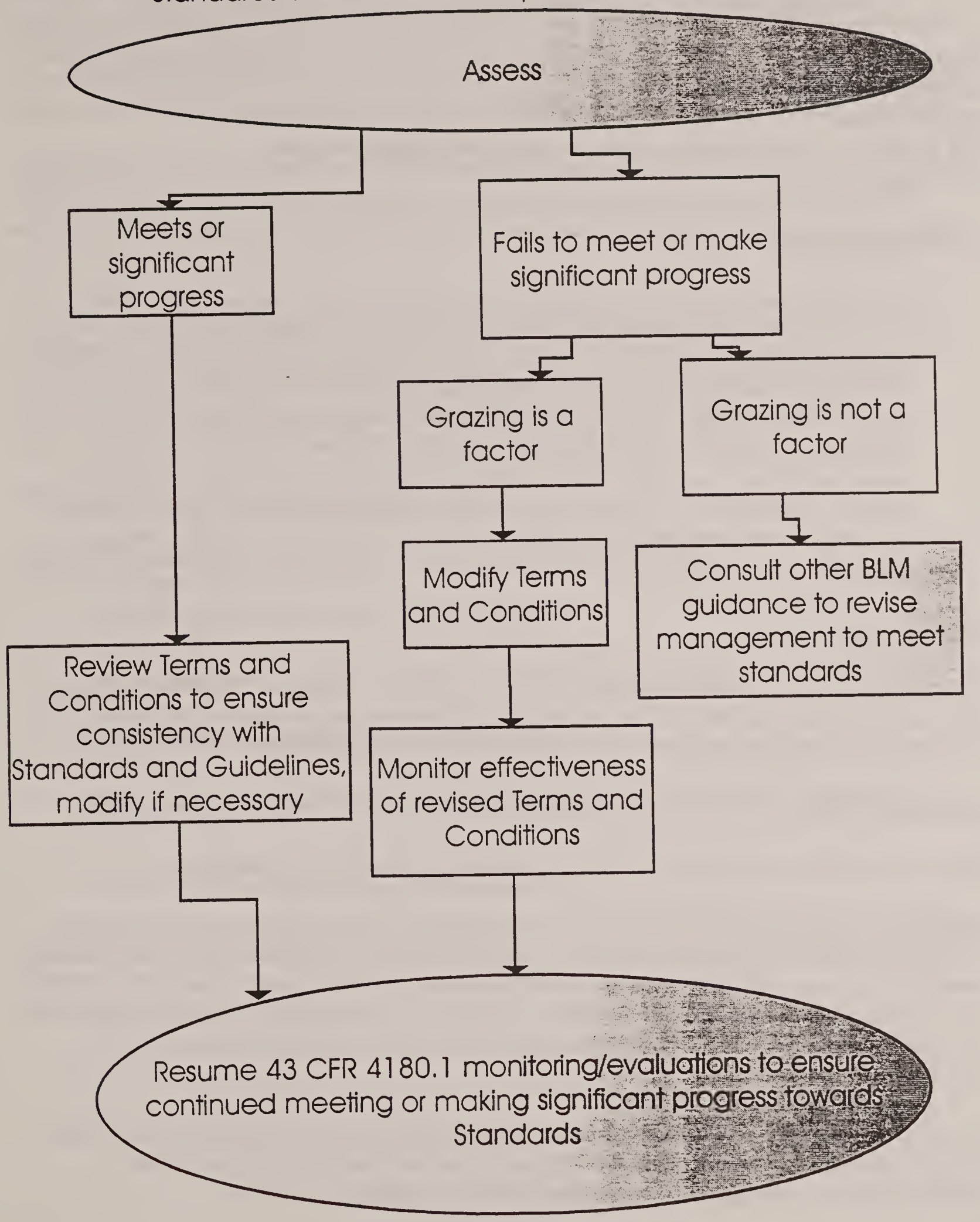
The attached DRAFT IMPLEMENTATION GUIDE, STANDARDS AND GUIDELINES FOR HEALTHY RANGELANDS and Standards and Guidelines Implementation Flow Chart is intended to assist managers and all employees responsible for implementing standards and guidelines.

Signed by:
Maitland Sharpe
Assistant Director
Renewable Resources and Planning

Authenticated by:
Robert M. Williams
Directives, Records
& Internet Group,WO540

2 Attachments
1 - The Standards and Guidelines Implementation Flow Chart (1 p)
2 - DRAFT IMPLEMENTATION GUIDE. (10 pp)

Standards and Guidelines Implementation Flow Chart



BUREAU OF LAND MANAGEMENT
DRAFT IMPLEMENTATION GUIDE
STANDARDS AND GUIDELINES FOR HEALTHY RANGELANDS

Sections

I. Policy Statement

The overall purpose of the standards and guidelines is, in working with permittees, lessees and the public, to make a difference on the land. The success will be measured in terms of concrete outcomes--not in terms of procedural actions. Success will be registered in recovering riparian areas, improved habitat conditions for wildlife, cleaner water, stabilized soils, robust native vegetation populations and sustainable livestock grazing operations. Procedural actions--plans written, data gathered, projects initiated, protests resolved or status reports--are merely means to an end. They are not, in and of themselves, the things about which our public cares. And they are not, in themselves, evidence of success. Our job is to change things on the land.

II. Definitions

Appropriate Action — means implementing actions pursuant to subparts 4110, 4120, 4130, and 4160 of [the grazing regulations] that will result in significant progress toward fulfillment of the standards and significant progress toward conformance with the guidelines. [4180.2(c)]

Authorized Officer -- is used to denote specific responsibilities of management personnel.

You -- means all personnel responsible for standards and guidelines implementation.

Standard -- Standards of rangeland health are expressions of levels of physical and biological condition or degree of function required for healthy, sustainable rangelands and define minimum resource conditions that must be achieved and maintained. Determination of rangeland health is based upon conformance with the standards. Application of the standard to the site considers the potential of the site without regard for the type or levels of use or management actions or decisions.

(Note: Standards may be supplemented with additional requirements where appropriate to meet resource objectives identified in an activity plan or land use plan. However, all resource objectives must, at a minimum, be consistent with the standards for the area.)

Guideline -- Guidelines for grazing management are types of grazing management methods and practices determined to be appropriate to ensure that standards can be met or that significant progress can be made toward meeting the standard. Guidelines are tools that help managers and permittees achieve standards. Guidelines implemented under 43 CFR 4180 are specific to livestock grazing. Guidelines are best management practices such as grazing systems, vegetative treatments, or improvement projects which could be used to achieve rangeland health standards.

Significant Progress--movement toward meeting standards and conforming to guidelines that is acceptable in terms of rate and magnitude. Acceptable levels of rate and magnitude must be realistic in terms of the capability of the resource, but must also be as expeditious and effective as practicable.

Significant Factor--a principal cause in the failure to achieve the standards and conform with the guidelines. A significant factor would typically be a use that, if modified, would enable an area to achieve or make significant progress toward achieving the standards. To be a significant factor, a use may be one of several factors contributing to less-than-healthy conditions; it need not be the sole factor inhibiting progress towards the standards.

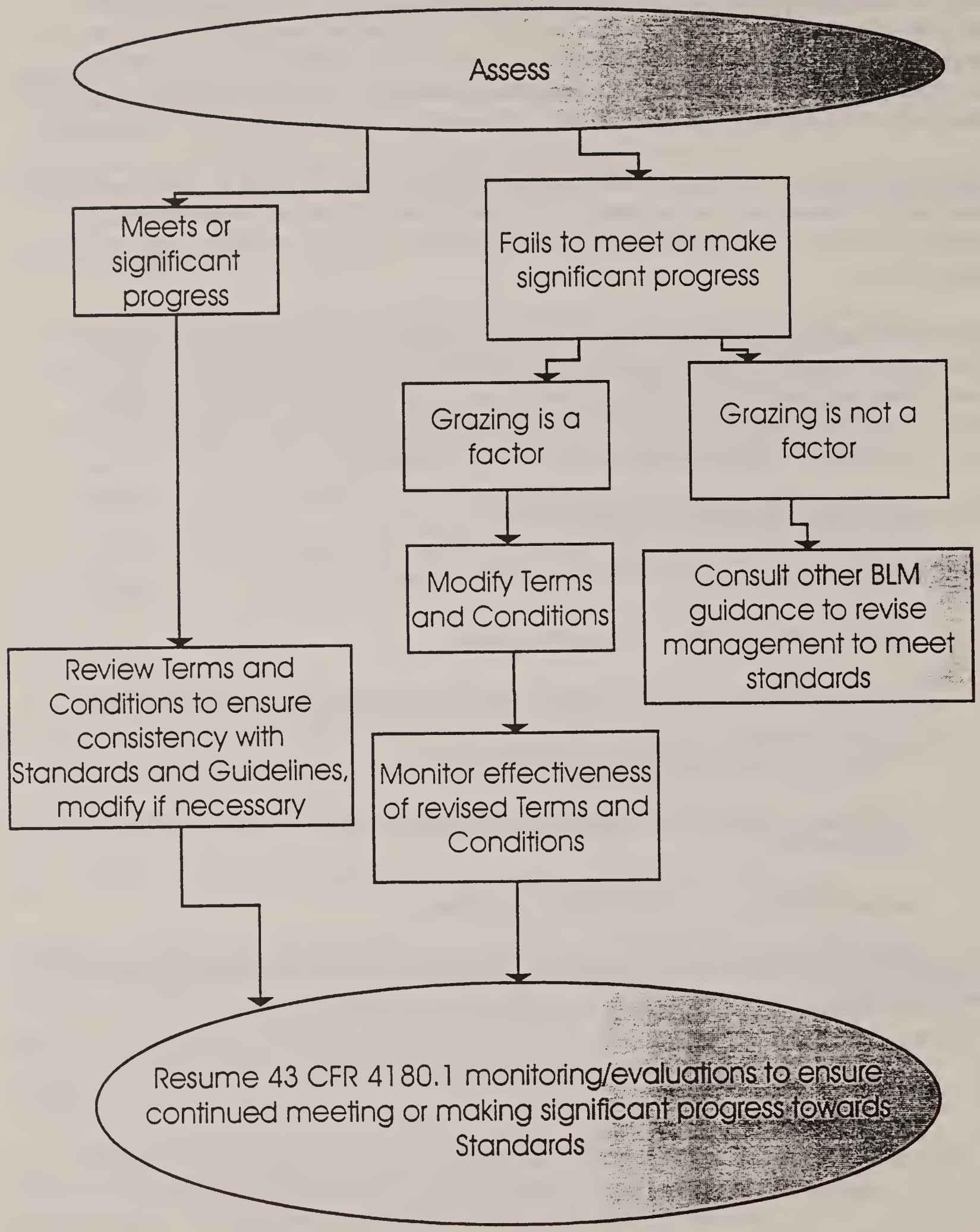
III. Standards and Guidelines Implementation

Implementing standards and guidelines requires that Authorized Officers--

1. prioritize areas and set an assessment schedule,
2. conduct assessments and make "meets, significant progress or fails" determinations,
3. if fails, determine if grazing is a significant factor,
4. if grazing is a significant factor, take appropriate action by modifying the terms and conditions, and
5. evaluate effectiveness of the revised management.

The Standards and Guidelines Implementation Flow Chart graphically portrays the sequence of implementation.

Standards and Guidelines Implementation Flow Chart



Each step in implementing the standards and guidelines is described in greater detail below.

1. **Prioritizing Areas and Setting Assessment Schedule**

Prioritize areas by allotments, groups of allotments, watersheds or other areas and set a schedule for addressing them, giving priority to areas believed to be at risk--in degraded condition or downward trend and in danger of losing potential.

The preamble to the 1995 grazing regulations states "...it is not possible to complete assessments of rangeland health and to take appropriate corrective action...immediately upon completion of the...standards and guidelines...The Department intends that assessments and corrective actions will be taken in priority order as determined by BLM."

Authorized Officers are responsible for determining the priority order for conducting assessments and carrying out needed actions. You must document a clear rationale for selecting the assessment priority and determining the schedule to follow in conducting assessments and taking appropriate actions.

The assessment must be completed in a reasonable time frame. In most States, Authorized Officers should ensure that at least ten percent of the livestock grazing lands under their jurisdiction are assessed each year until the initial round of assessments is complete. In States with an extremely large number of allotments, where assessing ten percent of the allotments per year would impose an impossible workload, a somewhat longer time-frame may be considered. In all States, the State Director should submit a draft implementation plan to the Assistant Director, WO-200 for approval, by August 1, 1998.

The process for prioritizing allotments or other areas must reflect the full range of physical and biological factors addressed by the standards. Previous allotment categorization (M, I, and C) may be useful in establishing priorities, but remember that the categorization process, in most cases, did not fully consider indicators of health and ecosystem function. For example, in determining the priority order for allotments or other areas, you should review the State 303(d) list. The Clean Water Act requires the State water quality management agency to bi-annually identify surface waters that are not meeting water quality standards. Priority should be given to allotments or areas where grazing-related water quality issues exist, particularly for those that lack the application of appropriate Best Management Practices (BMP). You should also review all areas with habitat for known threatened, endangered, or special status species and evaluate their priority for assessment and corrective action.

The renewal or transfer of a permit or lease may be an opportune time to conduct an assessment of rangeland health and make any needed changes in the terms and conditions. If you do not conduct an assessment of rangeland health when a permit or lease is renewed or transferred, you must include terms and conditions that ensure achievement of the standards and conformance with appropriate guidelines. These terms and conditions must include a statement that if an

assessment

results in a determination that changes are necessary in order to comply with the standards and guidelines, the permit (or lease) will be reissued subject to revised terms and conditions. Suggested language:

> *The terms and conditions of your permit (or lease) may be modified if additional information indicates that revision is necessary to conform with 43 CFR 4180.*

Authorized Officers may choose the allotment or a group of allotments as the basis for assessments or may use some other unit such as a watershed. The unit selected should have common resource characteristics at a scale appropriate to the complexity of the issues.

The process for prioritizing allotments or other areas must reflect the full range of physical and biological factors addressed by the standards. Previous allotment categorization (M, I, and C) may be useful in establishing priorities, but remember that the categorization process, in most cases, did not fully consider indicators of health and ecosystem function.

You should strive to involve affected permittees and lessees, interested publics, other units of government and Indian tribes throughout the assessments, including activities associated with prioritizing allotments.

2. Conducting Assessments

Following the priority schedule, conduct assessments to determine whether the areas are meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines.

The purpose of assessing an allotment, or other areas for rangeland health is to determine whether standards are being met and guidelines followed. Monitoring data collected in the past will often be an important source of information in conducting an assessment, but years of monitoring data are not a required for conducting an assessment.

"Assessment" means the analysis, synthesis and interpretation of information, including monitoring data, to characterize the health of an allotment or other management unit. It is similar to "evaluation", as frequently used in the rangeland management program. Gathering new information in the field may be necessary as part of the assessment process. "Monitoring" means the periodic gathering of information.

To determine whether current management is resulting in meeting the standards, you should use the best data and resource information available to you. This may include quantitative data from monitoring and inventories, qualitative information, professional knowledge, and knowledge provided by State agencies, public land users and others. You should gather additional field

information only where it is needed to determine if standards are being met and what appropriate action to take in order to move resource conditions toward the standards.

In limited cases, quantitative monitoring data, gathered over a period of years, may be essential in determining whether an area meets the standards or is making significant progress. It is anticipated that in these cases, it could take several grazing seasons to determine direction and magnitude of change. However, actions will be taken to establish significant progress toward conformance as soon as sufficient information is available to indicate a need for changes in grazing practices.

Quantitative monitoring data are not always required to make those determinations nor to implement actions to improve livestock grazing management. It would be inconsistent with our mandate to manage the public rangelands if we were to allow an allotment or watershed to deteriorate while prolonged monitoring studies are conducted. If reliable indicators of rangeland health demonstrate that areas are not meeting or not making significant progress toward meeting standards, you should take appropriate action.

If you determine that inadequate information is available to determine whether areas are meeting standards and conforming to guidelines or making significant progress toward meeting standards and conforming to guidelines, you should, without delay, initiate action necessary to gather the minimum information needed to make the determination. Generally, resource information or data collected should be tied directly to the standards and guidelines.

In assessing the health of rangelands to determine whether action of the authorized officer is necessary, consider the extent to which standards are being met and guidelines followed across the area of a grazing allotment or group of allotments. Failure to comply with a standard in an isolated area will not necessarily mean the area being assessed is failing to meet the standards or requires a corrective action. This exception would not apply if the isolated area is of significant ecological importance or if water quality standards are not being met.

At the end of the assessment, you must determine that the area being assessed --

1. meets the standards and conforms to the guidelines or is making significant progress toward meeting standards and conforming to guidelines, or

2. fails to meet the standards and conforms to the guidelines and is failing to make significant progress toward meeting standards and conforming to guidelines.

If you determine the area meets the standards and conforms to the guidelines or is making significant progress toward meeting standards and conforming to guidelines, you must--

1. review the existing terms and conditions to ensure that they will provide for continued achievement of (or progress towards meeting) the standards and guidelines, and

2. plan for monitoring and evaluation activities to provide long-term assurance that the area continues to meet, or make significant progress toward meeting, the standards.

If you determine the area fails to meet or make significant progress toward meeting the standards and conforming to the guidelines, you must proceed to step 3 below, "Determine If Grazing Is a Factor."

3. Determine If Grazing Is a Factor

For areas determined to be not meeting standards and conforming to guidelines and failing to make significant progress toward meeting standards and conforming to guidelines, determine if existing grazing management practices or levels of grazing use are significant factors in failing to achieve the standards and conform with the guidelines.

You should not assume that existing grazing management practices or levels of grazing use are significant factors in failing to achieve the standards and conform with the guidelines. You should determine if grazing is a factor only after reviewing the best data and resource information available to you. This may include quantitative data from monitoring and inventories, qualitative information, professional knowledge, and knowledge provided by public land users and others.

If inadequate information is available to determine whether current livestock grazing is a significant factor in failing to meet the standards for a priority area, you should, without delay, initiate action necessary to gather the minimum information needed to make the determination.

Determining if grazing is a factor should employ the minimum information needed to decide whether livestock grazing is a significant factor in the failure to meet the standards or conform to the guidelines. Collecting additional data in the field is not an end in itself. The goal is to use information to work with permittees, lessees and the public to improve resource conditions and to ensure that standards for rangeland health are being met at the earliest possible date.

If you determine that existing grazing management practices or levels of grazing use are significant factor(s) in failing to achieve the standards and conform with the guidelines, you must proceed to step 4 below, "Taking appropriate action by modifying the terms and conditions."

If you determine that existing grazing management practices or levels of grazing use are not significant factor(s) in failing to achieve the standards, you should consult other BLM guidance to revise management to meet the standards.

4. Taking appropriate action by modifying the terms and conditions

If existing grazing management practices or levels of grazing use are significant factors in failing to achieve the standards and conform with the guidelines, you must, in consultation with permittees, lessees, the State and interested public, take appropriate action and modifying the terms and conditions by the start of the next grazing season to ensure the terms and conditions result in meeting the standards and conforming to the guidelines or making significant progress toward meeting the standards and conforming to the guidelines.

Terms and conditions are the prescription for applying standards and guidelines to a specific permit or lease. For example, a standard to maintain healthy, productive plant and animal communities at viable population levels could be addressed by a guideline requiring appropriate rest during the growing season. A term and condition of the permit or lease may list specific dates pastures must be rested, or require the operator to follow a specific grazing plan.

Range improvement permits and cooperative range improvement agreements are also management tools used to improve resource conditions and achieve livestock management objectives. Range improvement projects must be consistent with standards and guidelines. Any range improvement permits and cooperative range improvement agreements must include terms and conditions needed to ensure achievement of, or at least show significant progress towards, meeting the standards and conforming with the appropriate guidelines. Authorized Officers should continue to evaluate range improvement projects based on their effectiveness to meet the rangeland health standards.

Appropriate action must be taken in cases where standards are not being met or when significant progress is not being made, and livestock use is found to be a significant contributing factor. Where appropriate action is needed, it may include adjusting the season or duration of livestock use; reducing livestock stocking rates; modifying or relocating range improvements; modifying or implementing grazing systems; implementing best management practices; or other such actions. Actions can be phased in as long as significant progress is achieved. In other words, it is not mandatory that actions result in immediate compliance with standards and guidelines, but it is mandatory to take action that will result in significant progress (as soon as practicable but not later than the start of the next grazing year.)

Appropriate action may also include implementing a management plan, such as a watershed-based allotment management plan or a functional equivalent (Coordinated Resource Management Plans, etc.). Implementing a management plan means taking action to bring grazing management into conformance with plan objectives, which in turn conform with standards and guidelines. Merely developing an implementation plan, implementation schedule, or monitoring schedule does not constitute an appropriate action. Management change must occur on-the-ground to constitute appropriate action.

To ensure compliance with water quality standards, you should review the State-approved BMPs and ensure that appropriate BMP components and protective measures are incorporated into terms and conditions of permits and leases.

A decision to modify the terms and conditions of a grazing permit or lease must be in conformance with the land use plan and must be supported by appropriate NEPA analysis. If the terms and conditions modifications have been previously addressed in the NEPA analysis for an allotment management plan, a similar type activity plan, or a related decision document, this NEPA analysis should be evaluated to determine its adequacy. If the previous analysis does not adequately cover the proposed terms and conditions modifications, a new NEPA document must be prepared. The new document may tier to, supplement, or incorporate by reference, parts of or all of an existing NEPA document.

5. **Evaluate Effectiveness**

Evaluate the effectiveness of management under the modified terms and conditions in meeting the standards and conforming to the guidelines. If further monitoring and evaluation indicate that the area has not achieved or is not making significant progress toward meeting the standards and conforming with the guidelines, further modify the terms and conditions by the start of the next grazing season, in consultation with permittees, lessees, the State and interested public, to ensure the terms and conditions result in meeting the standards and conforming to the guidelines or making significant progress toward meeting the standards and conforming to the guidelines.

After you have completed the initial assessment and taken appropriate action, gather information on a periodic basis to determine whether the appropriate action is achieving the desired resource conditions. Modify terms and conditions of the permit or lease, as needed, to achieve the standards and maintain significant progress toward the desired resource condition.

IV. Report

Authorized Officers must submit, by State, assessment progress each year as part of the National Rangeland Inventory, Monitoring and Evaluation Report.

Authorized Officers must submit, by State, the following information by October 15, of each year as part of the National Rangeland Inventory, Monitoring and Evaluation Report:

Assessment Category	Number Of Allotments Assessed		Number of Acres Assessed (Public)	
	Current Year	Cumulative	Current Year	Cumulative
Rangelands meeting all standards or making significant progress toward meeting the standards				
Rangelands not meeting all standards or making significant progress toward meeting the standards, but appropriate action has been taken to ensure significant progress toward meeting the standards (livestock is a significant factor)				
Rangelands not meeting standards or making significant progress toward meeting the standards --no appropriate action has been taken to ensure significant progress toward meeting the standards (livestock is a significant factor)				
Rangelands not meeting all standards or making significant progress toward meeting the standards due to causes other than livestock grazing				
Total assessed				
Total not assessed				
Total Allotments / Acres				

Appendix B - Rangeland Uses

Assessing the quality of rangeland soils: Challenges and opportunities

Jeffrey E. Herrick and Walter G. Whitford

Rangeland soils present unique challenges and opportunities for assessing soil quality. Three characteristics in particular distinguish rangeland soils from cropped soils: (1) spatial variability in rangelands tends to be higher than in cropped systems; (2) temporal variability is high because many biological and physical processes depend on a limited and frequently unpredictable supply of soil moisture; (3) the land often has many uses in addition to food production.

While all three characteristics present obstacles to the development of reliable soil quality indicators, each also presents additional opportunities. Patterns of both spatial and temporal variability can be quantifiable attributes of the system that may provide additional information about soil processes.

Conflicting definitions of soil quality are often implicitly, but not explicitly, based on a particular value or use. These conflicts may be resolved using an alternative paradigm in which soil quality is defined only with respect to the soil's capacity to fulfill clearly defined functions. Ratings for individual functions can then be compared for a variety of values and land uses.

Spatial variability

The spatial variability of many rangeland soil properties is extraordinarily high when compared with typical land under cultivation. This high level of variability occurs at a variety of scales, from regional to microsite.

At the regional level, rangelands may occur on all arable soils, as well as on soils which have little or no potential for crop production. In mountainous and arid regions, this may include land on which little soil development has occurred. On a smaller scale, a single management unit within a region may cover several square kilometers and include a wide variety of landforms and landscape positions spread over more than one watershed. Each unit may include several soil orders. Soil depth and summer soil water potential may vary by several orders of magnitude. The underlying natural variability associated with slope, aspect, and relative landscape position is confounded by a variety of anthropogenic influences. Information on land-use history, which could be used to help separate natural from anthropogenic influences and establish a baseline, is often limited, even on experiment stations.

Within a given landscape unit, it has been shown that soil properties are strongly correlated with shrub distribution in a variety of rangeland ecosystems. (Halvorson et al.; Parker et al.; Virginia and Jarrell). Significant differences in nutrient availability and soil water relations are also associated with animal tracks (Radcliffe), and ant and rodent mounds (Lobry de Bruyn and Conacher; Munson and Whiteford). At a still finer scale, even the decomposition of individual cattle dung patches can generate significant changes in surface hydrology (Herrick and Lal) (Figure 1).

Spatial variability in soil properties is clearly related to differences in soil and ecosystem functions. In many cases, relatively small areas make a large contribution to a particular function. For example, in arid and semi-arid mountainous regions, the majority of palatable biomass production often occurs on deep, well-watered riparian-zone soils. Likewise, a relatively large proportion of resource cycling in

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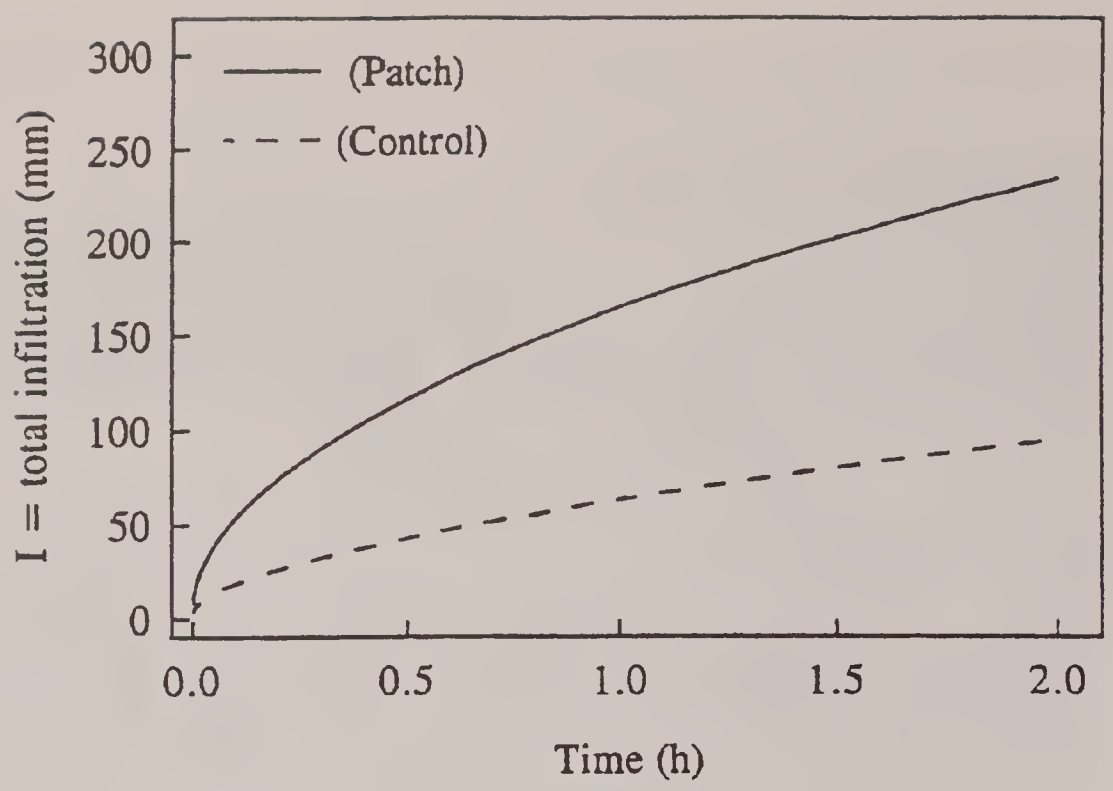

Figure 1. Cumulative infiltration based on double-ring tests compared for control and five month-old cattle dung patch microsites in a Costa Rican pasture (n = 4) (adapted from Herrick and Lal)

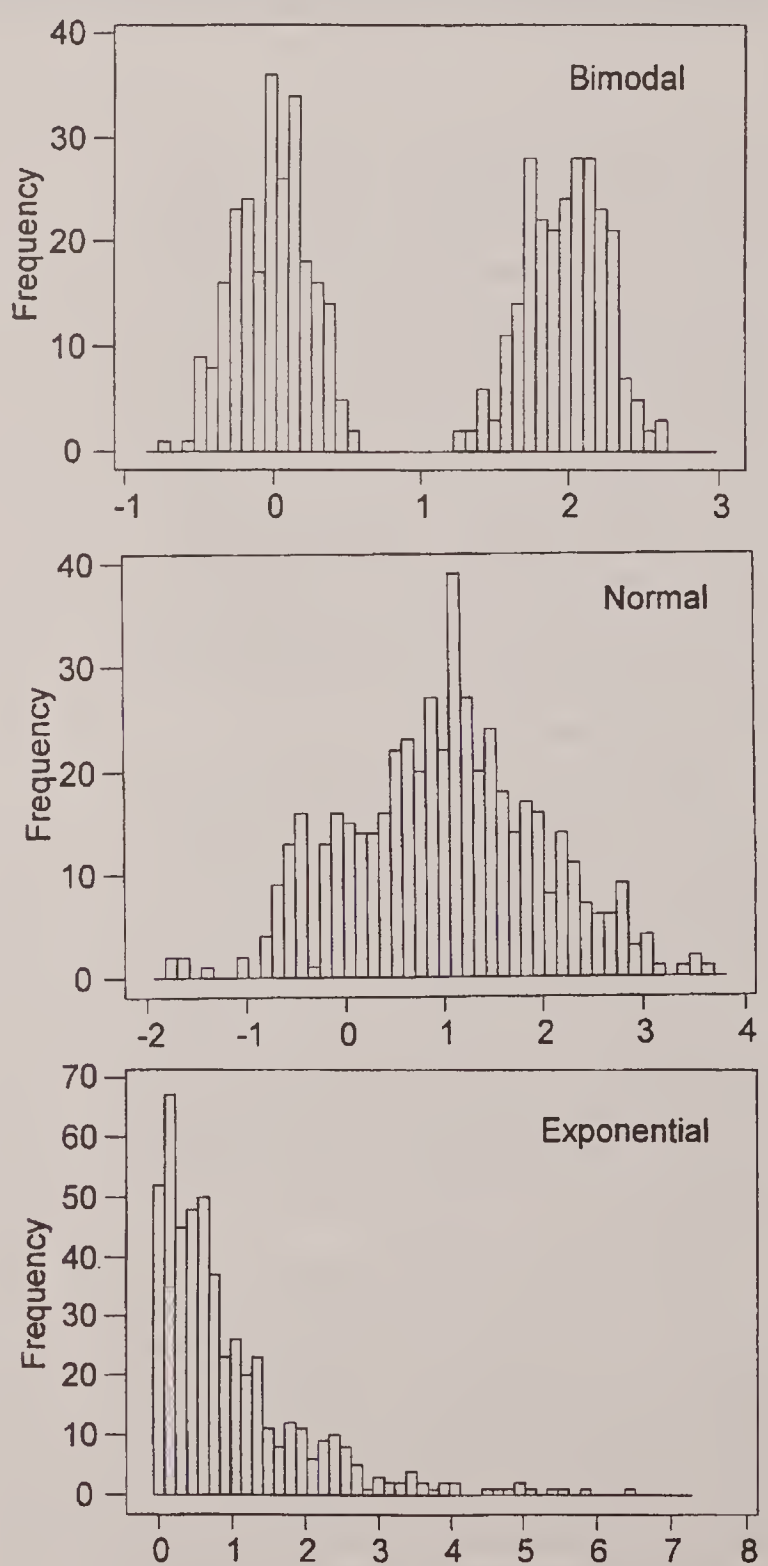

Figure 2. A selection of frequency distributions with mean and standard deviation both equal to one in all cases

shrublands occurs beneath shrub canopies and in the rhizosphere of widely-scattered grass clumps (Schlesinger et al.).

Challenges. A high level of spatial variability clearly presents a problem for sampling. Simple random sampling risks missing small areas that make a large contribution to ecosystem function. Even if these areas are included, a simple average across all landscape units and vegetation microsites may not accurately represent true soil quality at a site. For example, average soil properties could be quite similar for an annual grassland and for a shrubland, due to cancellation of values in shrub and intershrub spaces. Finally, the high level of variance associated with applying a random sampling pattern over a diverse system may make it nearly impossible to detect changes in soil quality without resorting to a level of replication which is beyond the budget of most programs.

Opportunities. While high spatial variability presents a problem for standard sampling and analysis approaches, variance can often be limited by careful stratification. Strata can be nested from the landscape to the microsite. Vegetation patterns and condition, landscape position, topography, parent material, and distance from disturbance foci can all be used at a variety of scales.

Sampling of a stratified design traditionally is based on the relative contributing area of each strata. However, efficiency may be increased by focusing on strata that make the greatest contribution to selected soil functions or are likely to show the greatest change in response to anticipated stressors.

Changes in soil quality in some strata may also indicate changes in other strata. For example, increases in soil depth in a depositional area could indicate increases in erosion rates on slopes above. Recent advances in geographic information systems (GIS) and landscape ecology facilitate identification of strata that are likely to be linked.

In some cases, the soil variability itself may serve as an indicator of how well the soil is performing selected functions. At least three measures of variability might be applied as indicators: (1) the coefficient of variation (CV), (2) ratios between strata, and (3) the scale at which variability occurs.

Coefficient of variation. The coefficient of variation is the ratio of the sample standard deviation to the sample mean expressed as a percentage. It is an indicator of the overall variability of the system. In some low quality sites, in which average resource availability is too low to support desired species, a high CV may indicate that the system is concentrating soil resources, creating favorable microsites for these species. A high CV at a finer scale may indicate that a variety of microsites are available for seedling establishment.

A more detailed analysis might include an ex-

amination of the shape of the frequency distribution of the data. A bimodal distribution with the two peaks separated by a relatively short distance could yield a similar CV to a normal distribution with long tails, or an exponential distribution (Figure 2). Each of these distributions suggests different patterns of resource availability.

Ratios between strata. In addition to examining the overall distribution, average values for individual strata may be compared directly. For example, land degradation in the Chihuahuan Desert is associated with increased resource concentration around the bases of shrubs (Whitford and DiMarco). The ratio of shrub vs. shrub interspace soil organic carbon is an indication of the level of degradation. As resource availability declines in the interspaces, grass establishment and survival decline, further reducing the resistance of the system to additional resource concentration beneath the shrubs (Figure 3). In other systems, increased resource concentration associated with tree and shrub invasion is considered to be positive.

Scale of variation. The statistical distribution of values for any given parameter can also be examined spatially. Geostatistics can be used to define the scales at which major changes occur (Halvorson et al.). While variability at the scale of shrub-intershrub spaces may indicate large degraded areas that are more susceptible to further erosion and degradation, variability at a scale of 10 to 50 cm may indicate a relatively stable system where perennials dominate over annuals, creating natural dams that slow the overland flow and allow infiltration to occur. Tongway in Australia and Imeson in Europe, among others, have suggested that the scale and pattern of variation in surface soil characteristics and vegetation provide excellent indicators of the capacity of the system to retain resources. A similar approach was supported in the National Research Council report on rangeland health and is included in continuing work on the WEPP model (Weltz et al.). It is currently under evaluation in a US-EPA project at the USDA-ARS Jornada Experimental Range in New Mexico.

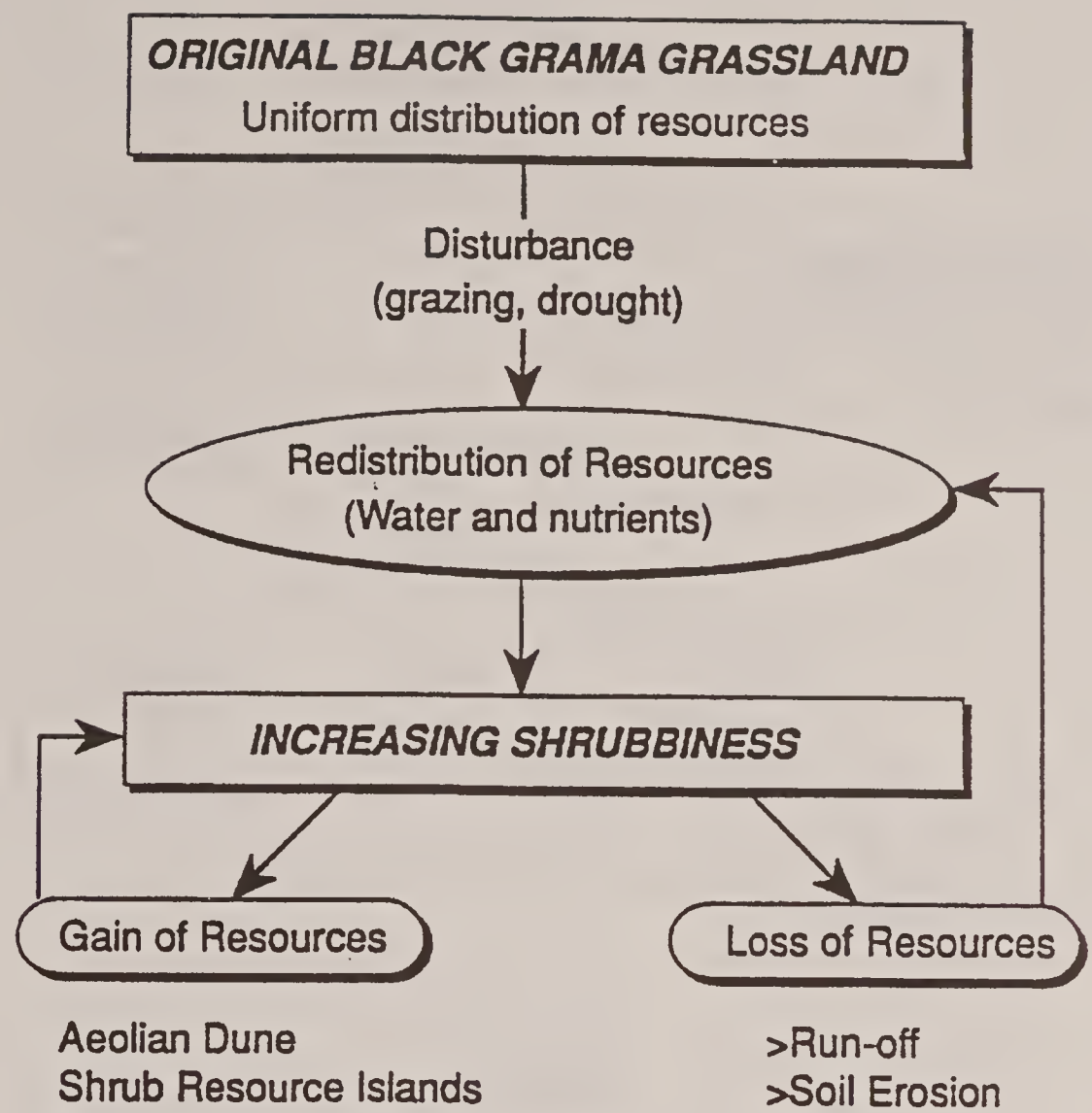

Figure 3. The Jornada model for desertification in the Chihuahuan desert

Temporal variability

Temporal variability in rangelands is high and relatively unpredictable. This is largely due to the strong dependence of many physical and biological processes on soil moisture in many rangeland systems. Most temperate rangelands are characterized by low and extremely variable annual precipitation and high summer evaporative demand. As a result, soil moisture is frequently limiting for both plant growth and soil biological activity, particularly during the growing season. When moisture is available, the response of soil organisms and, in turn, their effects on soil properties, depend on species composition and population structure (Figure 4). Species composition and population structure, in turn, depend on soil resource availability during previous seasons. These temporal patterns of biological activity directly affect soil nutrient mineralization and immobilization, aggregate formation and crust stabilization, and pore volume and continuity.

Physical processes in rangeland soils also vary in time as a function of soil moisture content and other factors (Parsons et al.; Warren et al.) (Figure 5). For example, during the winter of 1994, frost heave was relatively insignificant in southern New Mexico due to low surface soil moisture. Consequently, biological crusts remained largely intact. Conversely, precipitation was high during the winter of 1995, shattering the soil crust in many areas.

In addition to the temporal variability in static properties, the capacity of the soil to resist and recover from disturbance also varies in time, depending on the conditions present when the disturbance occurs (Warren et al.). This suggests that sampling timing relative to recent and historic weather patterns, disturbances, and conditions present at the time of disturbance may need to be considered when making a single-point-in-time assessment of soil quality.

Challenges. The challenges associated with sampling at any one particular time are similar to, and potentially greater than, the challenges

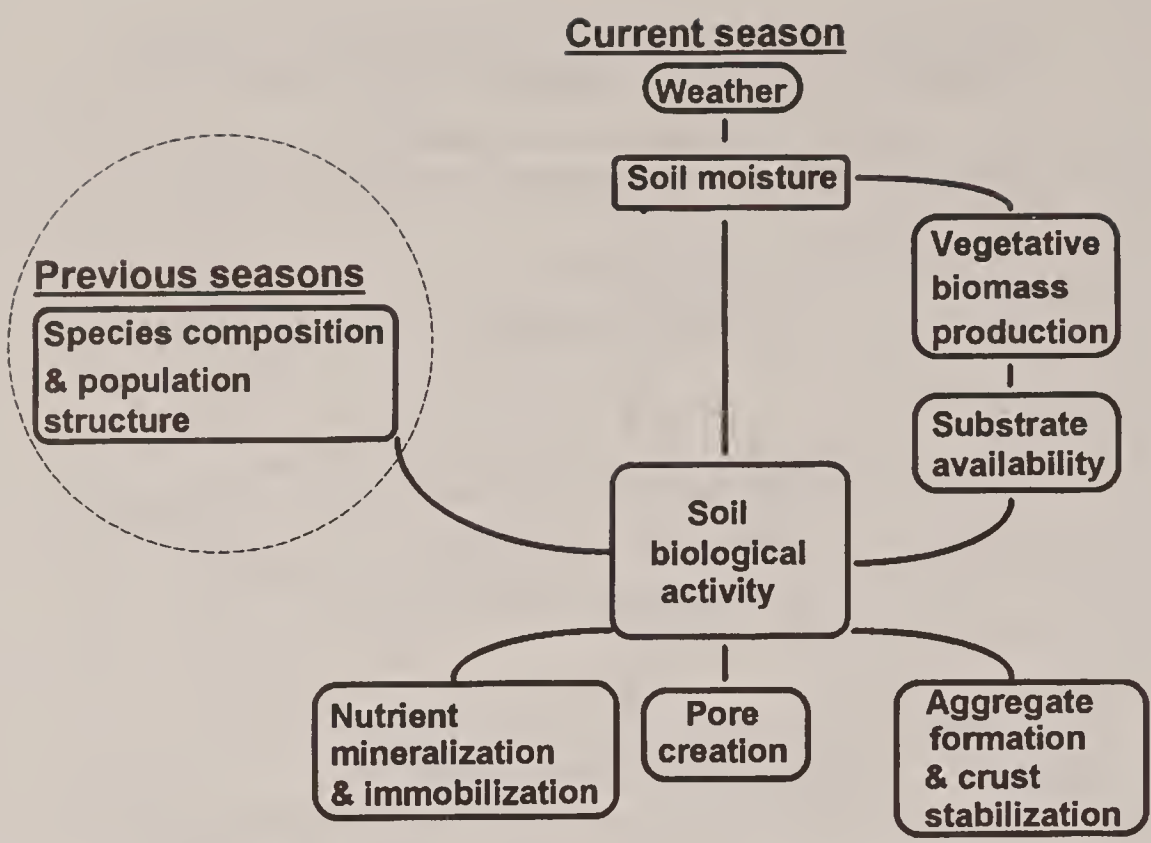

Figure 4. Dependence of biological modification of soil properties on temporal variability in soil moisture

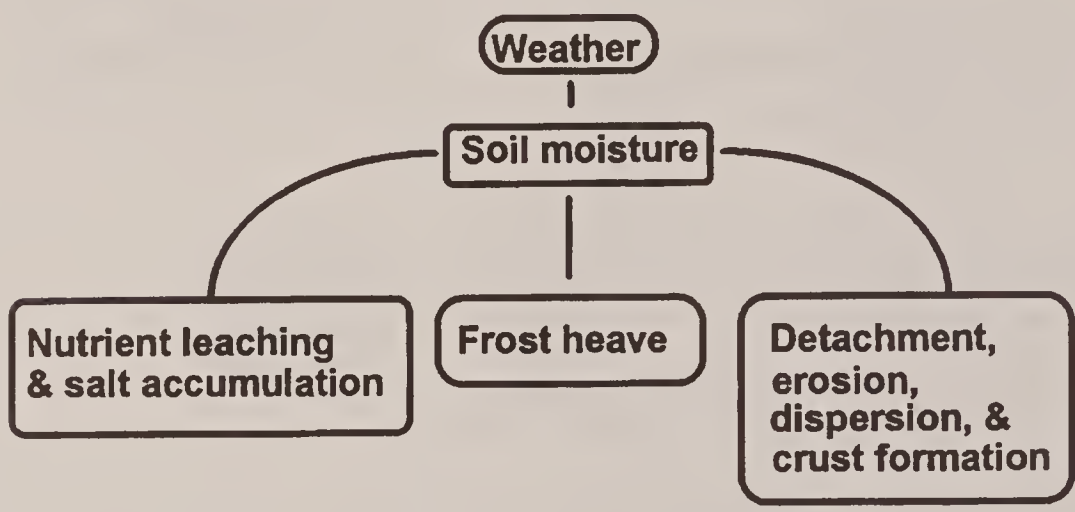

Figure 5. Dependence of physical modification of soil properties on soil moisture

of spatial sampling. The time scale of interest must be defined and the variability at the selected scale must be controlled.

Opportunities. At least four approaches may be taken to control variability within time periods. Each provides opportunities, although not without limitations: (1) restrict measurements to properties that are relatively insensitive to season and weather; (2) remove temporal variability through modeling; (3) sample frequently; (4) restrict sampling to defined periods.

Use only season and weather-insensitive properties. Some useful properties, such as the percentage of soil humus, or non-light fraction organic matter, are relatively stable to short-term environmental fluctuations (Theng et al.). However, many of the potential indicators that are most sensitive to changes in soil function are also sensitive to weather. Examples include aggregate stability and the ratio of soil microbial biomass carbon to total soil carbon. Ideally, indicators of soil quality should register changes in soil functions early in the degradation sequence, while intervention can still be effective.

Remove temporal variability through modeling. This is an increasingly viable option that has great potential for the future. However, our understanding of how soil processes vary over time and in response to weather is still limited. Furthermore, modeling is highly dependent on accurate site-specific weather information. This approach currently offers the greatest potential for long-term monitoring at sites with an existing research infrastructure and historical data. Modeling should increase in importance as our understanding of soil processes develops and weather data for remote sites becomes increasingly available through remote sensing technologies.

Sample frequently. Increasing sampling frequency is clearly an ideal approach when budgets permit. It yields the additional benefit of providing more information on the temporal dependence of soil properties.

Stratify sampling times. Sampling times can

Figure 6. A comparison of two alternative co-occurring systems, both of which could be described as having good soil quality. The system on the left is dominated by Lehmann lovegrass, an aggressive exotic which provides superior vegetative surface stabilization and resistance to grazing. These advantages come at the cost of reduced floral and soil faunal biodiversity, and reduced cover of more palatable native species found in the system shown on the right (Anable et al.)

be stratified by calendar date or, more effectively, by weather, biological cycles, or disturbance events. For example, surface bulk density might be determined in the fall prior to the first frost and in the spring soon after the last frost, while vascular cryptogam cover might be measured before and after grazing each year.

It may not be necessary to account for all periods of the year, particularly if only one period is critical for soil function or if properties covary through time. If controlling summer surface runoff is important, then making relevant hydrological measurements only during the summer may be sufficient.

Ratios of values determined at different times of the year may also prove useful. If nutrient retention in the system is an important function, or nutrients are particularly limiting, then the ratio of nutrient availability during periods of high and low plant uptake could be used. The idea of using the efficiency of coupling of energy and nutrient cycles is discussed in the National Research Council report on rangeland health.

Multiple use demands

Perhaps the greatest challenge to assessing soil quality for rangelands is that they are valued for a variety of different uses. Societal demands on nearly all agricultural lands have increased. In addition to food, fiber, and timber production, rangelands are valued for wildlife, biodiversity, recreation, watershed and groundwater protection.

Each use is associated with a different ideal vegetative community structure. Different communities are associated with different soil properties and spatial patterns of those properties. A thick O horizon may indicate good future timber production and surface stability to the forester, but is of little value to the rancher with a permit to graze the forested land. While the uniform soil surface stability provided by aggressive exotic grasses is highly valued by urban watershed and reservoir managers, the associated loss in soil and vegetative heterogeneity is regretted by many ranchers and biodiversity conservationists (Figure 6).

Challenges. A system for evaluating soil quality is needed that can be adapted to different values and uses without being biased toward the values associated with any single use. Continuing debate on whether or not a universal definition of soil quality exists may be relevant only for limited systems and closely-related uses.

Opportunities. An alternative to attempting to identify and calibrate universal indicators of soil quality is to simply develop indicators of specific soil functions. These indicators can then be combined using a variable-weighting system in which the weights reflect the requirements of different uses or values (Table 1). The indicators of soil function, in turn, are based on a variable-weighting combination of measurements of specific soil properties or processes. These properties and processes may be further subdivided using a system such as the one de-

Indicators Level 2	Indicators Level 1	Ecosystem Function/ Attribute	Societal Values/ Management Objectives
			+Productivity
			Food/fiber = f(I,II,IV)
			Wildlife = f(I,II)
1	A=f(1,2,3)	I=f(A,B)	
2			
3			
2	B=f(2,4)		+Biological Integrity
4			
			Biodiversity = f(. . .)
			Resistance to stress = f(. . .)
			Resilience to stress = f(. . .)
	B	III=f(C,D)	
	D		
			+Aesthetics
5	G=f(5,6)	IV = f(G, H)	
6			
			Wildlife = f(. . .)
			Vegetation patterns = f(. . .)
	H		
			Off-site
.	.	.	Water harvesting = f(. . .)
.	.	.	Flood/sediment control = f(. . .)
.	.	.	Climate change = f(. . .)

Table 1. Weighting system for combining indicators. Indicators can appear at any level and may contribute to more than one ecosystem function or attribute. Weights assigned at each level are flexible, allowing the system to be adjusted for different societal values and management objectives. Levels may be added to accomodate more complex indicator combinations. See (5) for a more complete description of a hierarchical system used to combine weighted indicators

veloped by Karlen et al. for no-till corn. Properties may contribute to more than one function or even more than once to the same function.

This systems modeling approach has three advantages over attempting to identify one or several universal indicators of soil quality. First, it is inherently flexible, particularly if it is set up in an interactive software environment. It can be easily adapted as our understanding of soil processes increases and can be modified for different ecosystems. Second, it forces both the designer and the user of the system to consider relationships between soil properties and soil quality. Third, this approach clarifies the distinction between relatively objective determinations of relationships between indicators and soil functions, and the relatively subjective selection of which use represents the highest value. It also clarifies the trade-offs in soil function which are necessary when managing for different values or uses.

Summary and conclusions

High levels of spatial and temporal variability increase the challenge of soil quality assessment in rangelands. Interpretation of the data is confounded by competing views on soil quality that are often related to the values that individuals place on the land. However, both the high level of variability and the multiple demands on the land can be viewed as opportunities to introduce new approaches.

Spatial variability can be used to generate indices based on the coefficient of variation, ratios between average values for different strata, and the scale(s) at which variation occurs within the system. By thinking of soil quality as an attribute of the ecosystem, as well as an attribute of single soil pedons, it may be possible to include more soil functions in our definition, more effectively. Ancillary information on the ecosystem, including management history, geomorphology, and vegetation patterns can be used to stratify and interpret soil information.

Temporal variability can also be turned to an advantage. The temporal patterns of the availability of different resources can be compared to determine how efficient the system is in utilizing and retaining resources.

Finally, the problem of multiple-use valuation of rangeland resources may be viewed as an opportunity to clarify the distinction between relatively objective determinations of soil function-indicator relationships and the relatively subjective selection of values. Much information on relationships between soil indicators and soil functions already exists. Future research clarifying these relationships may be linked to broader investigations of how various land uses affect and are affected by the integrity of specific soil functions. Interpretation of the results should be clearly separated into indicator-function and function-use relationships. This approach should reduce conflicts associated with indicator development based on values associated with a specific use.

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United States Department of Agriculture

Natural Resources Conservation Service

NRCS/RCA Issue Brief 6

November 1995

Grazing Lands

Did you know ...

...that nearly half of the lower 48 states is grazing land: range, pasture, hay, and grazed forest?

...that range, pasture, hay, and grazed forest land are located where they are primarily because of climate or topography and by landowners' decisions about land use?

...that properly managed grazing is one of the most energy-efficient ways of producing food and fiber?

...that grazing lands help improve water supplies for residential, commercial, agricultural, and recreational uses?

...that many wildlife species rely on grazing lands for habitat and food?

...that carbon sequestration (absorption of atmospheric carbon by soil and plants) occurs when farmers and ranchers practice good grazing land management? And that carbon sequestration is a key to mitigating climate change?

...that grazing lands could be developed by farmers and ranchers as a source of biomass energy and raw materials, which could reduce U.S. reliance on imported products?

Where are the U.S. grazing lands?

Grazing lands exist in every state, but the amounts and kinds of land and the uses, products, and values from grazing lands vary from state to state. Examples of grazing land include—

- annual grasslands of California;
- *hot* deserts in the southwestern states and *cold* deserts in the Great Basin;
- shrub-grasslands throughout the western states;
- prairie grasslands of the Great Plains and Corn Belt;
- humid grasslands of the eastern United States and Hawaii;
- tundra rangelands of Alaska;
- improved pasture and hay lands throughout the Intermountain West, Northern Great Plains, Great Lakes, Northeast, and South;
- wetlands and riparian areas in every state; and
- grazed forests in all states adjacent to and east of the Mississippi River and in the mountain states of the West.

Although some pasture and hay lands are managed as a monoculture, others—particularly rangelands—are complex mixes of species that offer increased plant, animal, and landscape diversity. Many eastern forests used for timber production are also grazed, particularly if the forest land type is suitable for livestock grazing and other forage, such as pasture or hay, is available.

How grazing lands have changed

During the first half of this century, most agricultural operations included both cropland and grazing land. Cattle, sheep, and goats often grazed land that could not or should not have been cultivated or otherwise used intensively. New technology and new marketing opportunities in the 1970's, however, encouraged farmers to plow lands that had not been previously cultivated. The result, in many places, was increased erosion on lands that formerly had been protected by grasses, legumes, and shrubs.

Although some runoff and erosion are natural, accelerated erosion on degraded land reduces the land's production potential and causes offsite damage from sedimentation in streams, rivers, lakes, and reservoirs. Accelerated erosion is a concern not only where grazing lands have been plowed, but also on lands that are grazed improperly. Improper grazing can lead to other detrimental environmental impacts. Twenty-five percent of the Nation's grazing lands need some form of conservation treatment to reduce erosion.

Why are grazing lands important?

Energy savings—Grazing animals eat plants that cannot be digested by humans and many other animals, and have the advantage of producing food and fiber with little expenditure of fossil fuel energy. On properly managed grazing land—including pastureland and hayland—only 1 calorie of fossil-fuel energy is needed to produce up to 2 calories of food and fiber energy. Many crops require from 5 to 10 calories of fossil-fuel energy for every calorie

of food or fiber produced. Improving the efficiency of grazing land production can increase landowners' income, improve environmental quality, and help reduce the Nation's dependence on imported fossil fuel.

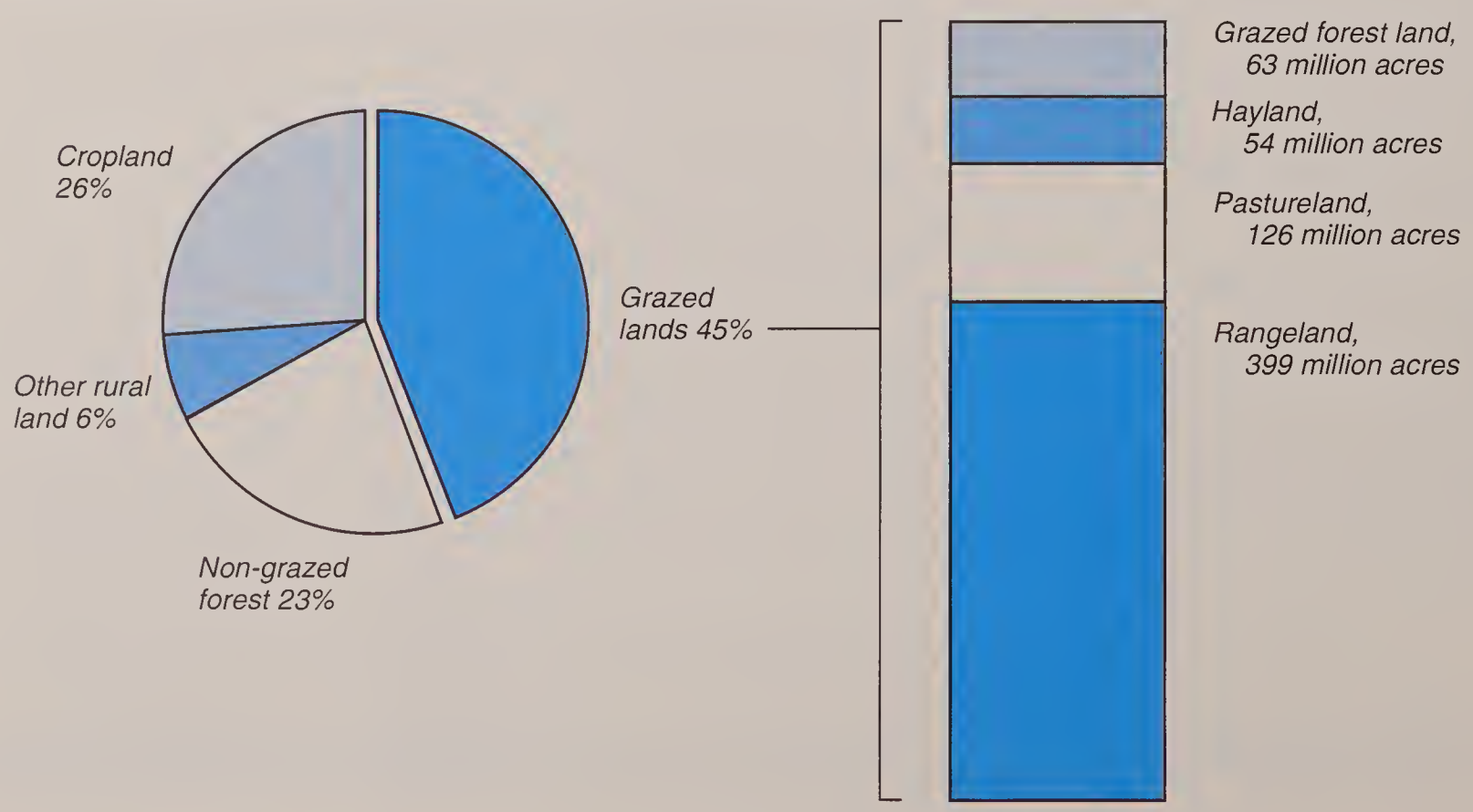
Food, medicine, and other products—Grazing by domestic livestock has been the primary use of grazing lands since European settlement and remains one of the most important uses today. Meat, milk, leather, wool, and mohair are well-known products from grazing animals. Less well known are pharmaceuticals produced from nonfood parts of the animals; natural fertilizers from animal bones, blood, and manure; and new and unique uses of familiar products—such as using wool, which readily absorbs oil, to remove spilled oil from soils, streams, lakes, and oceans.

Water storage and release—Vast quantities of rain and snow fall on the Nation's grazing lands. On healthy grazing lands, much of the water infiltrates into the soil and is used for plant growth, is stored in underground aquifers, or flows through the soil, providing water for streamflow, riparian areas, wetlands, and lakes, and subsequent use by people and wildlife.

Water quality—Modern grazing land management is one of the most important ways that farmers and ranchers can reduce erosion and water pollution and diversify income. For example, natural drainage areas on farms and the riparian areas adjacent to streams can be planted to grazing land plants. These forage plants capture runoff and sediment from the fields and protect water quality. Where sufficient plant material is left in grassed waterways or stream buffer zones for soil and water conservation purposes, a significant amount of the plant material can be grazed or mechanically harvested. There may also be outdoor recreation income options available—hiking, camping, horseback riding, hunting, and fishing.

Wildlife—Hunting and fishing are important recreational activities, and when many people think of wildlife they think of game species—deer, elk, grouse, or trout. But all wildlife have intrinsic value and are part of the ecological functioning of grazing lands. Everyone enjoys the unexpected view of a white-tailed deer on a pasture or grazed forest in the eastern United States, of an antelope in the Northern Great Plains or the Great Basin, of a pheasant in a grassed waterway in the Corn Belt, of a hawk in the desert Southwest, and of a mule deer on rangelands in any of the western states. People enjoy watching and listening to songbirds, and hearing—maybe seeing—a fish jump in a stream or pond. These experiences are made more enjoyable by the spectacular scenery that is often associated with grazing lands—the mountains of the West, the stark desert landscape of the Southwest, the prairie vistas of the Great Plains, and the green grass of pastures contrasted with the fall color of trees in the East.

Grazing lands make up 45 percent of U.S. non-Federal rural land.



Waste utilization—As concentrated animal production facilities—poultry and swine farms, beef feedlots, and confinement dairies—have become more common in a few geographical areas, and cities have begun to run out of landfill space, grazing lands have become attractive and appropriate locations on which to spread organic products and recycle the nutrients they contain. Spreading poultry litter on pasture land in the southern and eastern United States has allowed landowners to improve forage production and develop a more successful beef industry.

When properly applied, manure and other organic by-products can enhance the productivity and soil quality of grazing lands by increasing soil organic-matter content, improving soil moisture-holding capacity, and supplying valuable nutrients. If such by-products are applied to degraded land, or if they are applied in excess of the land's capacity to absorb them, the organic matter and nutrients from them can wash into streams, lakes, and estuaries, causing serious water quality degradation.

Carbon sequestration—Grazing land soils in the Great Plains contain over 40 tons of carbon per acre, while cultivated soils contain only about 26, on average. Carbon dioxide and other greenhouse gases may be increasing in the earth's atmosphere and changing the earth's climate. The grasses, legumes, and shrubs on grazing lands remove carbon dioxide from the air through photosynthesis and store it in the soil when roots die and decompose. This process promotes the long-term sequestration of carbon as soil organic matter. Cultivated lands planted to grassland plants as part of the Conservation Reserve Program were found to have added an average of 1,000 pounds of carbon per acre per year during the first 5 years after planting. This means that the CRP alone is removing 18 million tons of carbon from the atmosphere each year. This gain in sequestration of atmospheric carbon will continue until the soil reaches its equilibrium level of carbon.

Biomass—Grazing land plants can be harvested as sources for biomass energy or as feed stocks for industrial materials. There is a growing interest in using plant materials for energy because of the United States' dependence on foreign oil and concern about climate change associated with the release of fossil carbon into the atmosphere. Using *homegrown* plant material for energy would reduce to some extent the amount of oil that is imported. Burning plants for energy releases carbon dioxide into the air, but this carbon is offset by the carbon removed from the atmosphere through photosynthesis. Biomass carbon is, therefore, a renewable and sustainable resource.

Grazing land health

Good grazing land management often leads to a more productive mix of plants. Also, soils are less compacted and more protected from the erosive forces of wind or water, and the self-regenerative capacity of the land is improved. Collectively, this improvement is considered a gain in grazing land *health.* Loss of grazing land health means that some options for current and future uses of the land have been temporarily or perhaps permanently lost.

What causes loss of grazing land health? The most common reason is overgrazing by domestic and wild animals. Fortunately, *grazing lands can be maintained in a healthy state with grazing, and properly managed grazing can enhance ecosystem health.* Sheep grazing, for instance, can reduce the dominance of leafy spurge and other noxious weeds on rangelands and thereby promote greater biodiversity. In many parts of the country, livestock—cattle, sheep, and goats—graze in shrub- and forest-dominated ecosystems to remove and prevent the buildup of highly flammable material and reduce the likelihood of wildfire.

Riparian areas can be enhanced by grazing management and permanent vegetation cover.

Multiple benefits of grazing lands

Healthy grazing lands provide benefits other than feed for domestic animals. They are important habitats for a variety of large and small mammals, birds, and insects. Water runoff on healthy grazing land is slow, so more water infiltrates into the soil, providing cleaner, more abundant water for fish, wildlife, and human use. The plant cover on more than 600 million acres of grazing land sequesters millions of tons of carbon, thus reducing atmospheric carbon dioxide. Many grazing lands are among the Nation's most picturesque landscapes.

Although grazing lands are our biggest agricultural reserve, most of them are not suitable for crops. Nevertheless, some 180 million acres of non-Federal grazing lands—more than one-fourth of all privately owned grazing lands—are in soil capability classes I through III and therefore *could* be used to produce crops in the future if needed.

Healthy grazing land.

The United States Department of Agriculture, through the Natural Resources Conservation Service (formerly Soil Conservation Service), is preparing an environmental scan of the status, conditions, and trends of natural resources on America's non-Federal land, as required by the Soil and Water Resources Conservation Act of 1977 (RCA), Public Law 95-192. The appraisal will help guide the updating of the National Conservation Program, which directs USDA's natural resource conservation policies and programs. Ten other USDA agencies and 10 non-USDA agencies are full partners in this effort.

This issue brief is one in a series being prepared by the Natural Resources Conservation Service. It was prepared by Fee Busby, special assistant to the chief, Natural Resources Conservation Service, Washington, DC. For more information or if you have comments or suggestions, please contact James Maetzold, USDA, Natural Resources Conservation Service, Natural Resources Inventory Division, P.O. Box 2890, Washington, DC 20013; Phone (202) 720-0132; Fax (202) 690-3266.

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